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W. B. BIZZELL, President

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DIVISION OF CHEMISTRY

Relation of Soil Nitrogen, Nitrification and Ammonification to Pot Experiments

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BULLETIN No. 283. NOVEMBER, 1921.

RELATION OF SOIL NITROGEN, NITRIFICATION AND AMMONIFICATION TO POT EXPERIMENTS

BY

G. S. FRAPS.

It has been shown in a previous bulletin of this Experiment Station (No. 151 of 1912) that the nitrogen withdrawn from the soil by crops in pot experiments increases, on an average, with the total nitrogen of the soil. Yet it is well known, as pointed out in Bulletin 151, that the quantity of nitrogen taken from the soil by crops depends, to a considerable extent, upon other factors than the total nitrogen of the soil. The object of this bulletin is to study these relations, especially the relation between nitrate formation, or nitrification, and the nitrogen removed by crops in pot experiments.

In Bulletin 151, referred to above, 332 pot experiments were considered. It was found that there was a relation between the number of crops found deficient in nitrogen in pot experiments and the total nitrogen of the soil. The weight of the crops grown without nitrogen added to the soil increased with the nitrogen content of the soil up to the groups .06-.18 per cent., when it remained nearly the same; but the percentage of nitrogen in the crops increased, so that the quantity of nitrogen withdrawn by the crops increased with the percentage of nitrogen in the soils. The importance of estimating the nitrogen in the crops in such work was brought out, since the dry weight of the crop, considered without knowledge of its composition, was misleading.

The percentage of total nitrogen in the soil was thus an average indication as to the fertility of the soil with respect to nitrogen. When a sufficient number of soils were tested, the average amount of nitrogen withdrawn by crops was in proportion to the total nitrogen of the soil. This relation may not appear when only a few soils are studied; so the study of a large number of soils, as in Bulletin 151, was necessary.

While the above is true on an average, yet there are soils which deviate decidedly from the average, either above or below, and it is desirable to ascertain, if possible, the causes of such deviations in the pot experiments, and devise methods for following them and anticipating them, if possible. After the soils have been arranged in groups according to total nitrogen content, other characteristics may be studied, such as relation of surface to subsoil, acidity, and length of time the soil has been in cultivation.

While plants can take up organic nitrogenous compounds (Fraps, Principles of Agricultural Chemistry, pages 161, 219) as well as nitrates and ammonia, it is probable that cultivated plants absorb most of their nitrogen in the form of ammonia or nitrates, and the importance of the study of the quantity and formation of nitrates and ammonia is generally recognized. Extensive studies of nitrification and ammonification are being made from a variety of points of view by a number of workers. The object of our work is to study the relation between nitrification and ammonification and the nitrogen removed from the soil by

crops in pot experiments, with a view to a method for further separation of soils with similar total nitrogen content but different nitrogen response to crops.

In Bulletin 259 we showed that the average quantity of nitrates produced by the method there described increased with the total nitrogen of the soil, and, on an average, fairly constant percentages of nitrogen were converted into nitrates during the first twelve weeks. But there were wide variations in the individual soils; some did not nitrify at all, while the nitrification of others was much higher than the average. The addition of carbonate of lime to soils which failed to nitrify caused nitrification to take place. The nitrification of the organic matter of various soils was found to vary from 3.5 to 37 per cent. and the nitrifying capacity from 2 to 232. Soils with unusually low nitrification were mostly subsoils, and those with unusually high nitrification were also mostly subsoils. These and some other details presented in Bulletin 259 will be further considered in connection with the results presented in this bulletin.

METHOD OF WORK.

The method used for the pot experiments is described in Bulletins 127 and 145. In this work, pots of 5000 gms. soil were used, and additions of dicalcium phosphate for phosphoric acid and sulphate of potash for potash were made to the soils to be tested for nitrogen deficiency. Pots to which phosphoric acid, potash, and nitrogen as nitrate of ammonia were added, were used for comparison. No allowance was made for nitrogen in the seed, which would amount for corn to approximately .0225 gm. or 4.5 parts per million of the soil, and for sorghum .0150 gm. or 3 parts per million. The roots always were left in the pots.

Nitrates were determined in 500-gm. portions of the soils placed in percolators, and percolated at the beginning of the experiment and every four weeks thereafter, usually for twelve weeks, as described in Bulletin 259. The method for ammonia will be described on a later page.

Table 1. Relation of average of four crops to nitrogen of soil.

	Per cent nitrogen in soil	Average weight gm. per crop		Nitrogen per cent in crops	Nitrogen per crop gm.	Nitrogen per million per crop	Corn possibility of nitrogen per crop	No. of soils
		KPN	KP					
Group 1, Series 13, 0–.020 per cent nitrogen	.015	26.0	6.9	.73	.0463	9.3	12.4	4
Group 2, Series 9, 14, 15, 26, 31, .021–.040 per cent nitrogen	.033	25.4	7.4	.72	.0495	10.0	13.3	55
Group 3, Series 8, 12, 16, 22, 25, 32, 45, .041–.060 per cent nitrogen	.050	29.8	8.5	.69	.0546	10.9	14.5	54
Group 4, Series 18, 33, .061–.080 per cent nitrogen	.069	25.8	8.6	.77	.0635	12.7	16.9	30
Group 5 Series 3, 34, 21, .081–.100 per cent nitrogen	.092	32.3	13.2	.74	.0909	18.2	24.3	23
Group 6, Series 6, 20, .101–120 per cent nitrogen	.111	39.8	16.2	.72	.1205	24.1	32.1	9
Group 7, Series 7, 19, .121–.140 per cent nitrogen	.131	33.8	13.0	.76	.0978	19.6	26.1	12
Group 8, Series 35, .141–.160 per cent nitrogen	.152	36.0	17.9	.77	.1483	29.7	39.6	7
Group 9, Series 5, over .160 per cent nitrogen	.194	34.8	21.3	.84	.1973	39.5	52.2	8

RELATION OF THE CROPS TO THE TOTAL NITROGEN OF THE SOIL.

Table 1 gives the average results of four crops on each soil, the soils being arranged according to their nitrogen content. The difference between the groups is .02 per cent. soil nitrogen. The first group contains soils with 0 to .02 per cent. soil nitrogen but only four soils are found in this group. The second group, containing .021 to .04 per cent. nitrogen, contains 55 soils. The number of soils in the other groups may be seen in the last column of this table.

The average crops with the complete fertilizer, KPN, are less for the soils containing less than .08 per cent. nitrogen (Groups 1 to 4) than they are for the soils containing more than this amount of nitrogen. The soils containing more than .08 per cent. nitrogen seem to be, on an average, better adapted to the production of larger crops, even though all receive a complete fertilizer.

The average weight of the crops which receive phosphoric acid and potash, but no nitrogen, increases with the percentage of nitrogen in the soils, with the exception of Group 7, containing .12-.14 per cent. nitrogen, and including 12 soils. The difference between Group 3, containing .041-.060 per cent. nitrogen and Group 4 (.061-.08) is not great.

The average per cent. of nitrogen in the four crops is somewhat variable, although it is highest with Group 9, containing the largest percentage of nitrogen in the soil.

The average weight of nitrogen removed by the four crops increases with the percentage of nitrogen in the soil, with the exception of Group 7, containing .121-.140 per cent. nitrogen. The nitrogen removed per million of soil per crop increases in the same way, as it is merely the same figures expressed in a different way. This also refers to the corn possibility of the nitrogen per crop. This is the amount of corn which could be grown on two million pounds of the soil, if it used all of the nitrogen removed by these crops to advantage, and used 1.5 pounds nitrogen for a bushel of corn. The corn possibility varies from 12.4 to 52.2 bushels per two million pounds of soil, which is the weight of an acre to the depth of about 7 inches.

Table 2. Relation of average crops to nitrogen of soil, compared with previous work.

	Gm. nitrogen per crop		Parts per million per crop		Corn possibility bushels per 2,000,000 lbs.		Number of soils	
	Bull. 151	This work	Bull. 151	This work	Bull. 151	This work	Bull. 151	This work
Group 1. Nitrogen in soil 0-.020	.0284	.0463	5.7	9.3	8	12.4	9	4
Group 2. Nitrogen in soil .021-.040	.0471	.0495	9.4	10.0	12	13.3	17	55
Group 3. Nitrogen in soil .041-.060	.0681	.0546	13.6	10.9	18	14.5	27	54
Group 4. Nitrogen in soil .061-.080	.1207	.0635	24.1	12.7	32	16.9	13	30
Group 5. Nitrogen in soil .081-.100	.0995	.0909	19.9	18.2	26	24.3	12	23
Group 6. Nitrogen in soil .101-.120	.0991	.1205	19.8	24.1	26	32.1	5	9
Group 7. Nitrogen in soil .121-.140	.1404	.0978	28.1	19.6	37	26.1	9	12
Group 8. Nitrogen in soil .141-.160	.1183	.1483	23.7	29.7	31	39.6	7	7
Group 9. Nitrogen in soil .161 up...	.....	.1973	.....	39.6	.....	52.2	.....	8
Group 9. Nitrogen in soil .161 to .180.....	.2145	.....	42.9	.....	56	.....	3	.....
Group 10. Nitrogen in soil .181-.200	.4170	.....	83.4	.....	.....	.....	1	.....
Group 11. Nitrogen in soil .221 up...	.2995	.....	59.9	.....	.....	.....	2	.....

Table 2 compares the average results of this work with previous work published in Bulletin 151. As could be expected, the average quantities of nitrogen withdrawn per crop are not identical with those published in the previous bulletin for all crops. The amount withdrawn by Group 1, containing .021-.040 per cent. nitrogen is much less in the results published in Bulletin 151 than for the work here reported. The results of Groups 2, 3, and 5 are much closer.

Nitrogen removed in parts per million of the soil is a different way of expressing the *grams nitrogen removed per crop,* and the *corn possibility in bushels per two million pounds of soil.* When the corn possibilities are compared, comparatively close agreement is noted with Groups 2, 3, 5, 6, 8, and 9. It is, of course, impossible to expect exact agreement.

These results confirm the conclusions in Bulletin 151, that the average size of the crop, and the nitrogen withdrawn from the soil in pot experiments, increases with the total nitrogen of the soil.

RELATION OF THE DIFFERENT CROPS.

The average results of the first crops (corn) are given in Table 3. If this table is compared with Table 1, it is seen that the first crop is much larger than the average crop. In Group 1 the weight of the first crop without nitrogen is nearly three times that of the average crop. These differences are smaller with the succeeding groups, so that Group 9 is only 50 per cent. larger than the average. There are also wide differences in the percentage of nitrogen in the crops. The average nitrogen content is smallest with the first group and largest with the last group, and increases almost regularly between the first and the last. This causes larger differences between the nitrogen removed by the crops, whether expressed in weight of nitrogen, or parts per million of soil, than between the weights of the crops. While the weight of the first crop in Group 9 is only 50 per cent. more than the average, the amount of nitrogen withdrawn by the crop is more than twice the average.

Table 3. Average relation of the first crop, corn, to the soil nitrogen.

	Weight KPN crop gm.	Weight KP crop gm.	Per cent nitrogen in KP crop	Weight nitrogen gm.	Nitrogen parts per million	Ratio KPN:PK 100 to
Group 1. 0-.020 nitrogen	25.0	19.3	.57	.1200	24.0	77.2
Group 2. .021-.040 nitrogen	36.4	18.0	.62	0.1136	22.7	49.5
Group 3. .041-.060 nitrogen	37.3	19.8	.59	0.1190	23.8	53.1
Group 4. .061-.080 nitrogen	27.9	17.9	.87	0.1340	26.8	64.2
Group 5. .081-.100 nitrogen	33.6	25.0	.89	0.2055	41.1	74.4
Group 6. .101-.120 nitrogen	37.1	26.9	.96	0.2505	50.1	72.5
Group 7. .121-.140 nitrogen	36.5	24.3	.86	0.1994	39.9	66.6
Group 8. .141-.160 nitrogen	39.3	33.2	.95	0.3200	64.0	84.5
Group 9. Over .160 nitrogen	34.3	33.9	1.32	0.4407	88.1	98.8

The averages of the first crops without fertilizer do not increase as regularly with the soil nitrogen as the averages of four crops. This is the case also with the nitrogen taken up by the crop, although the relation in this case is more regular. The average weights of the first

crops without nitrogen, and the nitrogen withdrawn by the first crops, are not in as close relation to the average nitrogen of the soil as is the average of four crops.

The ratio of the crop with the complete fertilizer to the crop with phosphoric acid and potash only is given in the last column. Group 1 is out of relation to the others. With Group 2, the weight of the crop without nitrogen is 49.5 per cent. of the weight of the crop with the complete fertilizer. This ratio decreases almost regularly with the other groups until in the last group (Group 9) the crop without nitrogen is 98.8 per cent. of the crop with complete fertilizer.

Table 4. Average relation of the second crop, sorghum, to the soil nitrogen

	Weight KPN crop gm.	Weight KP crop gm.	Per cent nitrogen in KP crop	Weight nitrogen gm.	Nitrogen parts per million	Ratio KPN:PK 100 to
Group 1. 0-.020 nitrogen	20.1	2.6	.87	.0250	5.0	12.9
Group 2. .021-.040 nitrogen	24.6	3.9	.85	0.0357	7.0	15.9
Group 3. .041-.060 nitrogen	26.9	4.0	.79	0.0313	6.3	14.9
Group 4. .061-.080 nitrogen	25.1	5.8	.87	0.0477	9.5	23.1
Group 5. .081-.100 nitrogen	27.6	13.0	.86	0.0701	14.0	47.1
Group 6. .101-.120 nitrogen	35.6	12.1	.68	0.0758	15.2	34.0
Group 7. .121-.140 nitrogen	29.1	10.9	.83	0.0866	17.3	37.5
Group 8. .141-.160 nitrogen	35.4	13.8	.83	.1227	24.5	39.0
Group 9. Over .160 nitrogen	39.7	23.3	.69	0.1517	30.3	58.7

Table 4 gives the average results of the second crop, which was sorghum. The average weights with complete fertilizer in the first five groups were decidedly below those of the last four. The weights of the crops without nitrogen are below the average of four crops. The difference is greatest with the first three groups, which are less than half the average of four crops. With the other groups, the differences are not so great. The differences between the first crop and the second crop are quite large. With soils containing from 0 to 0.020 per cent. nitrogen, the second crop is about one-seventh of the first crop. With the soils containing the greatest amount of nitrogen, Group 9, the second crop is about two-thirds of the first crop.

Similar differences are observed when the weights of nitrogen removed, or nitrogen in parts per million are compared. These differences are not the same, however. In Group 1 the nitrogen removed by the second crop is one-fourth of the first, while the weight of the crop is one-seventh. With Group 9, the amount of nitrogen removed by the second crop is one-third of the first, but the weight of dry matter is two-thirds of the first crop.

The ratios of the crops with complete fertilizer to crops with no nitrogen are wider for the second crops than for the first. While the first crop in Group 2 (.021-.040 per cent. soil nitrogen) averages 49.5 per cent. of the crop with complete fertilizer, the second crop averages only 15.9 per cent. While the first crop in Group 9, containing over .16 per cent. nitrogen, is 98.8 per cent. of the crop with the complete fertilizer, the ratio of second crop is only 58.7.

There is thus a decided falling off from the first crop to the second crop, both in the amount of the crop and the amount of nitrogen taken

from the soil. The average relations between the total nitrogen of the soil and the nitrogen removed by the crops are closer for the second crops than for the first crops. The growth of the first crop apparently removes the more available nitrogen and this varies in soils containing the same total nitrogen. After the more available nitrogen has been removed by the first crop, the average nitrogen removed by the second crop is more nearly in proportion to the total nitrogen of the soil.

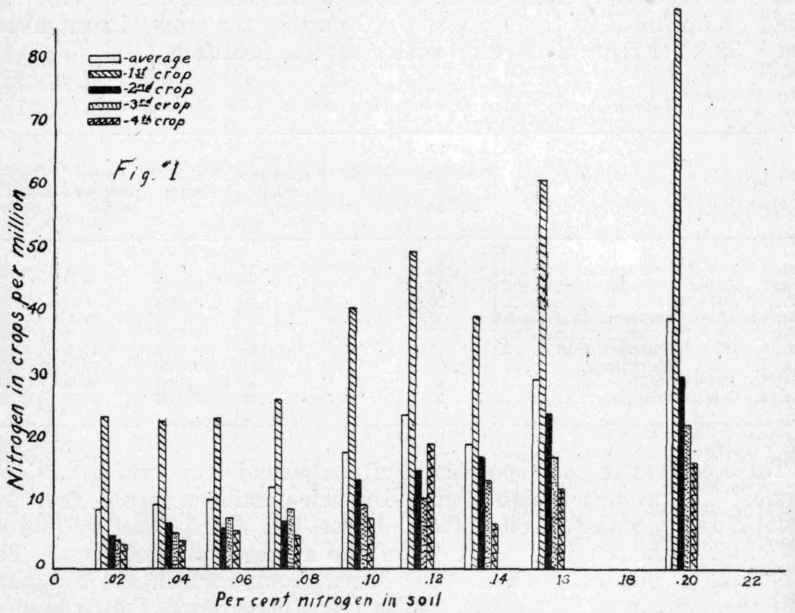

Figure 1—Relation of nitrogen in soil to nitrogen removed by crops.

This seems to be the explanation for the differences between these two crops. It is quite possible that drying the soil and otherwise preparing it in the laboratory has rendered part of the soil nitrogen more active, and enabled it to produce a larger first crop than would have been the case had the soil been placed in the pot in a damp condition as it was taken from the field. There is evidence from other investigations that this may be the case.

Table 5. Average relation of the third crop, corn, to the soil nitrogen.

	Weight KPN crop gm.	Weight KP crop gm.	Per cent nitrogen in KP crop	Weight nitrogen gm.	Nitrogen parts per million	Ratio KPN:PK 100 to
Arrangement						
Group 1. 0-.020 nitrogen	33.0	3.6	.63	.0222	4.4	10.9
Group 2. .021-.040 nitrogen	32.2	4.8	.58	0.0276	5.5	14.9
Group 3. .041-.060 nitrogen	34.4	6.9	.58	0.0397	7.9	20.1
Group 4. .061-.080 nitrogen	29.7	7.3	.61	0.0468	9.4	24.6
Group 5. .081-.100 nitrogen	36.9	8.6	.58	0.0498	10.0	23.3
Group 6. .101-.120 nitrogen	45.9	11.1	.52	0.0567	11.3	24.2
Group 7. .121-.140 nitrogen	37.3	11.8	.58	0.0698	14.0	31.6
Group 8. .141-.160 nitrogen	36.8	15.4	.59	0.0878	17.6	41.8
Group 9. Over .160 nitrogen	37.5	15.8	.64	.1130	22.6	42.1

Table 6. Average relation of the fourth crop, sorghum, to the soil nitrogen.

	Weight KPN crop gm.	Weight KP crop gm.	Per cent nitrogen in KP crop	Weight nitrogen gm.	Nitrogen parts per million	Ratio KPN:PK 100 to
Group 1. 0-.020 nitrogen	26.2	2.2	.86	.0180	3.6	8.4
Group 2. .021-.040 nitrogen	18.7	2.8	.81	0.0211	4.2	15.0
Group 3. .041-.060 nitrogen	20.6	3.2	.81	0.0283	5.7	15.5
Group 4. .061-.080 nitrogen	20.4	3.6	.73	0.0253	5.1	17.6
Group 5. .081-.100 nitrogen	31.1	6.2	.61	0.0383	7.7	19.9
Group 6. .101-.120 nitrogen	40.4	14.6	.70	0.0989	19.8	36.1
Group 7. .121-.140 nitrogen	32.1	4.9	.78	0.0354	7.0	15.3
Group 8. .141-.160 nitrogen	32.3	9.1	.69	0.0626	12.5	28.2
Group 9. Over .160 nitrogen	27.8	12.2	.72	0.0837	16.7	43.9

Tables 5 and 6 contain the results of the third crop of corn and the fourth crop of sorghum. In the first four groups, the weights of the third corn crop are larger than the weights of the second sorghum crop, but the plants contain smaller percentages of nitrogen, so that the amount of nitrogen taken up is less for the third crop of corn than for the second crop of sorghum. With the last five groups, the weight of the corn crop averages less than the weight of the second sorghum crop, and the amount of nitrogen removed is decidedly less for the third crop of corn than for the second crop of sorghum. The differences between the second crop and the third crop are much less than the differences between the first crop and the second crop.

The weights of the fourth crop of sorghum are less than the weights of the second crop of sorghum, or the third crop of corn. Here again the differences are not as great as between the first and second crops.

Table 7. Comparison of four crops, (first crop 100), grown on soils grouped by nitrogen content.

	Weight of PK crops				Nitrogen in crops			Ratio KPN:KP			
	Crop 1	Crop 2	Crop 3	Crop 4	Crop 2	Crop 3	Crop 4	Crop 1	Crop 2	Crop 3	Crop 4
Arrangement.											
Group 1. .0-.020 nitrogen	100	13.5	18.7	11.4	20.8	18.5	15.0	77.2	12.9	10.9	8.4
Group 2. .021-.040 nitrogen	100	21.7	26.7	15.6	31.4	24.3	18.6	49.5	15.9	14.9	15.0
Group 3. .041-.060 nitrogen	100	20.2	34.8	16.2	26.3	33.3	23.8	53.1	14.9	20.1	15.5
Group 4. .061-.080 nitrogen	100	32.4	40.8	20.1	35.6	34.9	18.9	64.2	23.1	24.6	17.6
Group 5. .081-.100 nitrogen	100	52.0	34.4	24.8	34.1	24.2	18.6	74.4	47.1	23.3	19.9
Group 6. .101-.120 nitrogen	100	45.0	41.3	54.3	30.3	22.6	39.5	72.5	34.0	24.2	36.1
Group 7. .121-.140 nitrogen	100	44.9	48.6	20.2	43.4	35.0	17.8	66.6	37.5	31.6	15.3
Group 8. .141-.160 nitrogen	100	41.6	46.4	27.4	38.3	27.4	19.6	84.5	39.0	41.8	28.2
Group 9. .161-.180 nitrogen	100	68.7	46.6	36.0	34.4	25.6	19.0	98.8	58.7	42.1	43.9

Table 7 contains a comparison of the four crops and gives the weights of the crops without nitrogen, the nitrogen in the crops compared with the first crop as 100, and the ratio of the crops with the complete fertilizer to the crops without nitrogen. This table brings out clearly the relation between the first crops and the succeeding crops. The weights of the second crop of Group 1 is only 13.5 per cent. of the first crop, and the fourth crop is 11.4 per cent. of the first crop, while for Group 9, the second crop is 68.7 per cent of the first crop and the fourth crop is 36 per cent of the first crop. The differences are not so great when the nitrogen in the crops is considered. The nitrogen of the second crop of Group 1 is 20 per cent. of the first crop, while that of Group 9 is 34.4 per cent. The nitrogen removed by the fourth

crop of Group 1 is 15 per cent. of that removed by the first crop, and that of Group 9 is 19 per cent.

It is evident that different conclusions may be drawn concerning the deficiency of soils for nitrogen in pot experiments depending upon whether only one crop is considered, or whether the averages of several successive crops are taken. If one crop only is considered, the soil will seem to give larger crops and yield greater quantities of nitrogen than if several crops are grown.

To illustrate further: the four soils containing 0 to 0.020 per cent. nitrogen of Group 1 gave up in the *first* crop, on an average, 24 parts nitrogen per million of soil, which is equivalent to 32 bushels of corn to the acre of two million pounds. The average corn possibility of *four* crops is 12.4 bushels, while the corn possibility of the *second* crop would only be 6.7 bushels per two million pounds. The soils of Group 9, containing over .16 per cent. nitrogen, gave up 88 parts per million to the first crop, equal to a corn possibility of 117 bushels; the corn possibility for the average of four crops is 52 bushels and that for the second crop is 40 bushels. This is for an acre of soil about 7 inches deep. It would be twice this for 14 inches of soil, and three times this for 21 inches of soil.

A soil may appear deficient in nitrogen in pot experiments and yet not appear deficient in the field. The requirements of the crop in the pot experiments may exceed the field possibility, limited by soil depth or by moisture, soil condition, insect pests, or other circumstances.

Any conclusion as to the need of these soils for nitrogen would, therefore, vary to some extent with the number of crops considered. In our opinion, the results of the first crop are better than the production of the various soils in the field would justify. The results of the second crop are probably lower, on account of the high quantities of nitrogen withdrawn by the first crop.

Another fact brought out in this work is the importance of estimating the amount of nitrogen in the crops in work of this kind, and of basing the opinion of the results of the pot experiment upon the amount of nitrogen taken out, and not upon the total weight of the dry matter. This is best illustrated by some individual tests, which are accordingly given in Table 8. It is seen from the examination of this table that crops nearly the same weight of dry matter may vary decidedly in content of nitrogen, and therefore in the amount of nitrogen withdrawn from the soil.

Table 8. Variation of nitrogen in certain crops.

	Weight KPN crop gms	Weight KP crop gms.	Per cent nitrogen in crop	Grams nitrogen in crop	Nitrogen per million by the crop
Soil 875, first crop, corn	15.9	19.6	2.66	.5214	104.3
Soil 875, second crop, sorghum	32.6	20.7	0.53	.1097	21.9
Soil 877, first crop, corn	11.8	10.0	2.42	.2420	48.4
Soil 877, third crop, corn	20.9	13.4	0.71	.0951	19.2
Soil 879, first crop, corn	11.9	20.5	1.56	.3190	63.9
Soil 879, third crop, corn	46.3	3.4	0.59	.0201	4.0
Soil 897, first crop, corn	48.9	33.5	0.59	.1976	39.5
Soil 962, first crop, corn	14.7	21.5	1.12	.2408	48.2
Soil 962, third crop, corn	15.6	4.5	0.54	.0243	4.9
Soil 1056, first crop, corn	47.4	38.9	0.66	.2567	51.3
Soil 3334, first crop, corn	42.9	20.5	0.41	.0841	16.8
Soil 7613, first crop, corn	32.1	13.1	2.00	.2620	52.4

With soil 875, the first and second crops are nearly the same in weight, but the nitrogen is 104.3 and 21.9 parts per million. The first crop of corn on soil 877 weighs less than the third crop, but the first crop removed over twice as much nitrogen. The first crop on soil 3334 is much larger than on soil 7613, but three times as much nitrogen is removed by the crop from soil 7613.

Table 9. Relation between total nitrogen in soil and that removed by four crops.

	Per cent nitrogen in soil	Per million removed by four crops	Per cent of soil nitrogen removed
Group 1	.015	37.2	25
Group 2	.033	40.0	12
Group 3	.050	43.6	9
Group 4	.069	50.8	7
Group 5	.092	72.8	8
Group 6	.111	96.4	9
Group 7	.131	78.4	6
Group 8	.152	108.8	7
Group 9	.194	158.0	8

Table 9 shows the relation between the average percentage of nitrogen in the soil, the parts per million of nitrogen removed by four crops, and the percentage of soil nitrogen removed by the first crop. The four crops removed 25 per cent. of the total nitrogen present in the first group of soils and 12 per cent. of the total nitrogen present in the second group of soils. These quantities are evidently unusually high, but the nitrogen in the seed (3 to 4.5 parts per million per crop) could account for part of this nitrogen. With the other groups, the nitrogen removed by the four crops is 6 to 9 per cent. of the total nitrogen of the soil. The amount of nitrogen given up to a single crop would thus average 1½ to 2 per cent. of total nitrogen of the soil, but might be much larger when the soil is first placed under cultivation.

RELATION OF SURFACE SOIL TO SUBSOIL.

Table 10 contains a comparison of the surface soils and the subsoils by groups. The weight of the first crop without nitrogen, the weight of the second crop without nitrogen, the average weight of all crops without nitrogen, and the average nitrogen removed per million by all crops are given. In almost every group the surface soils produce on an average better than the subsoils. In some cases the differences are small but in other cases the differences are quite large. Group 6 is the only apparent exception, but only one subsoil is present in this group. On an average the nitrogen of surface soils is better taken up by the crops than the nitrogen of subsoils.

Table 10. Surface soils and subsoils.

	Surface soil	Subsoil
Group 1. 0-.020 Nitrogen.		
Number of soils	0	4
Group 2. .021-.040 Nitrogen.		
Number of soils	25	32
First crop KD gm	20.8	15.8
Second crop KD gm	5.2	2.9
Average all crops KD gm	9.0	5.8
Nitrogen per million—average all crops	11.03	8.63
Group 3. .041-.060 Nitrogen.		
Number of soils	37	17
First crop KD	20.8	17.7
Second crop KD	4.4	3.3
Average all crops KD	9.1	8.0
Nitrogen per million—average all crops	11.41	9.99
Group 4. .061-.080 Nitrogen.		
Number of soils	10	22
First crop KD	22.1	16.0
Second crop KD	7.1	5.1
Average all crops KD	10.9	7.8
Nitrogen per million—average all crops	12.73	13.04
Group 5. .081-.100 Nitrogen.		
Number of soils	8	15
First crop KD	27.1	23.9
Second crop KD	10.5	6.1
Average all crops KD	14.8	15.3
Nitrogen per million—average all crops	19.45	17.49
Group 6. .101-.120 Nitrogen.		
Number of soils	8	1
First crop KD	29.0	29.9
Second crop KD	13.0	5.0
Average all crops KD	16.6	18.8
Nitrogen per million—average all crops	20.98	22.78
Group 7. .121-.140 Nitrogen.		
Number of soils	10	2
First crop KD	26.4	13.7
Second crop	12.5	4.0
Average all crops KD	14.1	6.8
Nitrogen per million—average all crops	21.22	10.57
Group 8. .141-.160 Nitrogen.		
Number of soils	5	2
First crop KD	34.9	28.9
Second crop KD	15.1	10.5
Average all crops KD	18.3	15.7
Nitrogen per million—average all crops	32.80	20.63
Group 9. Over .160 Nitrogen.		
Number of soils	7	1
First crop KD	34.9	26.7
Second crop KD	25.3	9.0
Average all crops KD	21.0	12.2
Nitrogen per million—average all crops	39.05	18.58
Average by groups—First crop	27.0	21.6
Second crop	11.6	5.7
Average all crops	14.2	11.3
Nitrogen per million	21.1	15.21

ACID SOILS COMPARED WITH NON-ACID SOILS.

Table 11 contains a comparison of acid soils and non-acid soils. The acidity was determined by the Veitch method. In some groups the results are decidedly in favor of the non-acid soils; in other cases there is little difference, and in others the acid soils produce better. In about half the groups the non-acid soils do better, and in about the other half there is little or no difference, or the acid soils do better. Some of the groups do not contain enough of the two kinds of the soils to make satisfactory averages. On an average by groups, the non-acid soils produce better than the acid soils.

Table 11. Comparison of acid and non-acid soils.

	Acid soil	Non-acid soil
Group 1. 0-.020 Nitrogen.		
Number of soils	1	3
First crop KD gm	14.5	20.8
Second crop KD gm	1.0	3.1
Average all crops KD gm	4.9	7.6
Nitrogen per million—average of all crops	5.76	10.43
Subsoils	1	3
Group 2. .021-.040 Nitrogen.		
Number of soils	13	44
First crop KD	17.8	18.0
Second crop KD	2.4	4.4
Average all crops KD	6.2	7.5
Nitrogen per million—average all crops	7.52	13.05
Subsoils	10	22
Group 3. .041-.060 Nitrogen.		
Number of soils	9	43
First crop KD	20.1	21.3
Second crop KD	4.2	4.1
Average all crops KD	6.3	8.5
Nitrogen per million—average all crops	12.03	10.95
Group 4. .061-080 Nitrogen.		
Number of soils	6	26
First crop KD	19.2	17.6
Second crop KD	4.3	6.2
Average all crops	7.6	4.1
Nitrogen per million—average all crops	9.61	13.72
Subsoils	3	19
Group 5. .081-.100 Nitrogen.		
Number of soils	2	21
First crop KD	16.8	25.8
Second crop KD	6.8	7.7
Average all crops KD	11.6	15.5
Nitrogen per million—average all crops	26.60	17.37
Subsoils	2	13
Group 6. .101-.120 Nitrogen.		
Number of soils	2	7
First crop KD	21.8	31.2
Second crop KD	15.9	11.0
Average all crops KD	16.7	17.0
Nitrogen per million—average all crops	11.54	24.70
Subsoils	0	1
Group 7. .121-.140 Nitrogen.		
Number of soils	4	8
First crop KD	27.8	22.6
Second crop KD	12.9	10.2
Average all crops KD	13.8	12.4
Nitrogen per million—average all crops	24.73	16.80
Subsoils	0	2
Group 8. .141-.160 Nitrogen.		
Number of soils	0	7
First crop KD	.....	.....
Second crop KD	.....	.....
Average all crops KD	.....	.....
Nitrogen per million—average all crops	.....	.....
Group 9. Over .160 Nitrogen.		
Number of soils	0	8
Average by groups.		
First crop KD gm	19.7	22.5
Second crop KD gm	6.8	6.7
Average all crops KD gm	9.6	10.4
Nitrogen per million—average all crops	13.97	15.29

In considering the effect of the acidity on the crop growth it is difficult to tell how much of this effect is due to being a subsoil and how much is due to acidity. The acidity may be one of the characters of the subsoil which decrease the growth compared with the surface soil. For this reason all of the acid soils in Groups 2, 3, and 4 were grouped into surface soils and subsoils. The averages are given in Table 12. These are all acid soils.

Table 12. Comparison of acid subsoils and acid surface soils.

		Number averaged	Per cent nitrogen	First crop gm. KD	Second crop gm. KD	Average all crops gm. KD	Nitrogen per million average all crops
Group 2.	Subsoil	10	.034	18.0	2.0	5.9	7.45
	Surface soil	3	.035	17.0	3.6	7.0	7.76
Group 3.	Subsoil	5	.046	20.2	3.4	7.6	13.23
	Surface soil	6	.042	18.8	4.8	8.5	9.17
Group 4.	Subsoil	3	.067	13.0	1.3	4.4	4.55
	Surface soil	3	.068	25.4	7.2	10.7	14.66

When the first crop is considered, the surface soil averages decidedly better than the subsoil with one group; a little better with another; and not as well with a third.

When the second crop is considered, the surface soils average better than the subsoils in all three groups. With the average of all crops, the surface soils average better than the subsoils in all groups. When the nitrogen removed is considered, the surface soil is decidedly better than the subsoil in one group, there is little difference in another group, and the subsoil is better than the surface soil in the other group.

These averages are not at all conclusive. While the surface soils seem to give up nitrogen better than the subsoils on an average, and non-acid soils average better than acid soils, yet subsoils are erratic, and some may be much better than the corresponding surface soil, while others may be much poorer.

RELATION OF COMPOSITION OF SOILS TO NITROGEN WITHDRAWN BY THE CROPS.

Table 13 shows the average relation of the chemical composition of the soils to the nitrogen withdrawn from four crops. The soils are arranged in groups according to the amount of nitrogen taken up by the four crops grown on them. For example, Group 1 contains soils which yield less than .030 gm. nitrogen to the four crops. Group 2 contains soils which yield .0301-.0490 gm. nitrogen to four crops.

Table 13. Average relation of composition of soil to nitrogen withdrawn by four crops.

Group Limits	Per cent N in soil	Gm. KD crop		Gm. N crop		Active P_2O_5 in soil p. m.	Acid consumed in soil	Lime in soil, per cent	Nitrification	Number of surface soils	Number of subsoils
		First crop	Average 4 crops	First crop	Average 4 crops						
Group 1. 0-.0300	.034	11.7	4.3	.0556	.0244	24.4	1.5	0.20	11.2	0	18
Group 2. .0301-.0490	.050	15.4	6.5	.0804	.0383	63.6	25.5	2.82	31.1	28	31
Group 3. .0491-.0675	.066	20.7	9.2	.1256	.0568	90.8	18.5	1.26	41.8	22	11
Group 4. .0676-.0865	.075	26.8	11.4	.1690	.0776	103.4	16.6	2.77	49.2	11	6
Group 5. .0866-.1050	.074	31.1	13.6	.2242	.0954	96.0	27.7	5.02	65.0	11	7
Group 6. .1051-.1240	.098	26.7	14.8	.2161	.1136	81.7	12.9	1.59	62.7	6	5
Group 7. .1241-.1430	.093	25.1	14.1	.3242	.1298	32.4	28.4	2.25	112.0	3	1
Group 8. .1431-.1615	.096	33.4	16.4	.3436	.1515	48.2	36.2	2.92	105.9	2	2
Group 9. .1616-.1800	.121	25.3	16.0	.3644	.1688	89.3	23.0	1.42	113.4	7	1
Group 10. .1801-.2796	.127	35.7	22.1	.5366	.2337	160.5	19.4	.77	141.5	7	2

The average percentage of nitrogen in the soil increases with the amount of nitrogen taken up by the four crops, except with Groups 5, 7, and 8.

The weight of the first crop, in grams, increases up to the fifth group, and is then irregular.

The average weight of the four crops in grams increases with the amount of nitrogen taken up by the crops except Groups 7 and 9.

The amount of nitrogen taken up by the first crop increases with the average nitrogen taken up by the four crops, with the exception of Group 6. The increase is not in the same proportion as the average of the four crops.

The active phosphoric acid increases from 24 parts per million in the first group to 90 parts per million in the third group, and is then irregular, decreasing to 36 parts per million in Group 7 and 48 parts per million in Group 8. No regular relation is to be observed.

The acid consumed is lowest with the first group, after which it is irregular. The lime is lowest with the first group, after which it is irregular. The nitrification increases with the amount of nitrogen taken up by the crops, with the exception of Groups 6 and 7, which are out of line. These nitrification data are the results published in the previous bulletin, No. 259, and constitute the quantity of nitric nitrogen produced in the soil during a period of twelve weeks, not including the nitric nitrogen present in the soil at the beginning of the experiment.

CORRELATION BETWEEN THE NITROGEN CONTENT OF THE SOIL AND THE NITROGEN TAKEN UP BY THE CROPS.

Mathematical methods are used in studying the correlation between various characteristics in biological work. The degree of correlation between two organs cannot be secured by measuring a single pair only. It is the correlation in the long run which must be considered, and the biologist must deal with masses and with averages. In Bulletin No. 267 of this Station, the correlation factor R between total phosphoric acid of the soil and the average phosphoric acid taken up by four crops, was found by Humbert to be .4495. Between active phosphoric acid and the phosphoric acid taken up by four crops, the factor R was found to be .5656.

The methods used for the study of correlation are well adapted to certain kinds of chemical work, for the reason that they not only show the average results but also the relation between the results.

The correlation between the total nitrogen of the soil and the nitrogen taken up by four crops (average per crop) is given in Table 14.

Table 14. Correlation Table between total nitrogen in soil and average nitrogen removed by four crops.

Nitrogen removed by crop	Nitrogen in soil. .015	.025	.035	.045	.055	.065	.075	.085	.095	.105	.115	.125	.135	.145	.155	.165	.175	.185	.195	.205	.215	.225	.235	.245	Total
.02				2		1	1																		4
.03	1	5	6	2				1																	15
.04	1	2	9	9	8	5	2						1												37
.05			3	8	6	5		1	3			1													27
.06			3	1	3	3	2	2		2															16
.07					1	4	1	2				1	1		1										11
.08		1		4		3	1			1			2												12
.09	1		1	1	1		1		3	1				1											10
.10			1	2	2	1									2		1								9
.11				4					1	1		1												1	8
.12				1				1		1	2		1		1										7
.13					2									1											3
.14							1				1														2
.15							1									1									2
.16					1						1														2
.17												1		1											2
.18			1						1		1	1						2							6
.19																									
.20																									
.22																									
.23									1	1															2
.24																				1					1
.25																2									2
.26																									
.27																									
.28															1				1			1			3
Total	3	8	24	34	24	22	10	7	9	7	5	5	5	3	5	3	1	2	1	1		1		1	181

The maximum group content only is given in the headings of the table; thus the second column includes soils with .016-.025 per cent. nitrogen. The coefficient of correlation R as calculated by the method given in Davenport's Principles of Breeding, page 465, for the above table is .653±.029. If there is a perfect correlation, R would be 1. If there is a perfect negative correlation, R would be —1. If there is no correlation, R would be 0. The nearer R approaches +1 or —1, the closer the correlation.

There is a closer correlation between the total nitrogen of the soil and the nitrogen taken up in the four crops than the total phosphoric acid of the soil and the phosphoric acid taken up by the four crops, or the active phosphoric acid, and the phosphoric acid taken up by the four crops, since .653 represents closer correlation than .47 or .57.

The correlation between the total nitrogen of the soil and the nitrogen taken up by the first crop is given in Table 15, and the factor R as calculated from this table is .581±.033. Our previous discussion leads us to expect that there would be a closer relation between the total nitrogen of the soil and the average nitrogen taken up by four crops than between the total nitrogen of the soil and the nitrogen taken up by the first crop, and this is shown correct by the correlation coefficient.

Table 15. Correlation Table. Relation between total nitrogen of the soil and nitrogen removed by the first crop.

Nitrogen in first crop.	Nitrogen in soil																								Total
	.015	.025	.035	.045	.055	.065	.075	.085	.095	.105	.115	.125	.135	.145	.155	.165	.175	.185	.195	.205	.215	.225	.235	.245	
.02																									
.04				3								1													4
.06	1	4	4	3	2	2	1	1					1												19
.08	1	1	11	9	3	2	2		1																30
.10		2	3	7	8	8																			28
.12				2	5	4	3	1	2			1													18
.14			1	2	1	3		1					1		1										10
.16			1		1		1	3		3	1		2												12
.18						2			2	2		1		1	1										9
.20		1	2						2																5
.22				2			1	1							2										7
.24			1						1								1							1	4
.26				3	1							1													5
.28	1			1	1						1			1											6
.30					1					1		1													3
.32				1			1				1														3
.34													1												1
.36				1	1		1									1									4
.38										1															1
.40																									0
.42																		1							1
.44											2							1							3
.46																									0
.48																						1			1
.50														1											1
.52																									0
.54			1																						1
.58															1	1			1			1			4
.68									1							1									2
	3	8	24	34	24	21	10	7	9	7	5	5	5	3	5	3	1	2	1	0	0	2	0	1	181

RELATION OF PRODUCTION OF NITRATES TO THE RESULTS OF THE POT EXPERIMENTS.

Samples of the soils used in the pot experiments were placed in percolators and subjected to nitrification. To 500 gms. of the soil, 0.2 gm. dicalcium phosphate and 0.2 gm. potassium sulphate were added, these additions having been made in the same proportions to the soils in the pot experiments. The percolation and nitrification were then carried out as described in Bulletin 259, page 10.

One series of these experiments was run exactly parallel with the pot experiments. The soils were weighed out, percolated on the date that the pots were planted, and then every four weeks thereafter. Other samples of the same soil were weighed out, water added in quantity equal to one-third the saturation capacity of the soil, and water added every other week to replace loss in weight. When the corn in the pots was harvested, these soils in the percolators were percolated and the nitrogen determined. The water conditions were, of course, not the same as in the pot experiments, for the reason that the plants were continually withdrawing the water from the pots, and more had to be added, while in the percolators water was lost only by evaporation, and there was much less variation.

The nitrogen present as nitrates at the beginning of the experiment was added to the quantity found during the test, and the total represents the nitrogen as nitrates which could be placed at the disposal of the plants if the process of nitrification in the pots should be exactly the same as the process of nitrification in the percolators.

Table 16 shows the results of five series of these experiments. The soils were run in groups containing similar quantities of total nitrogen.

Table 16. Relation of nitrogen removed by crops to nitric nitrogen formed in parts per million.

Soil No.	Removed by		Total	One percolation when corn cut	Found in percolation			Per cent nitrogen in soil
	Corn	Sorghum			0 to 8 weeks	8 to 16 weeks	Total 0 to 16 weeks	
7350	16.4	3.4	19.8	13.0	12.7	5.1	17.8	.024
7345	20.1	7.9	28.0	19.1	19.0	14.1	33.1	.039
7348	16.1	3.7	19.8	12.8	12.6	7.6	20.2	.029
7715	11.1	4.2	15.3	1.1	6.3	5.1	11.4	.032
7706	18.9	8.3	27.2	23.0	19.1	15.0	34.1	.038
7707	14.6	4.2	18.8	11.4	13.0	7.1	20.1	.027
7344	14.5	2.8	17.3	13.1	12.5	6.9	19.4	.037
7156	71.4	5.1	76.5	47.4	66.0	19.3	85.3	.037
7253	9.4	4.6	14.0	12.6	7.0	3.8	10.8	.026
7164	7.8	1.6	9.4	12.9	9.4	1.8	11.2	.038
7231	31.0	4.5	35.5	13.3	12.5	7.2	19.7	.028
Average	21.0	4.6	25.6	16.3	17.3	8.5	25.8	.032
7340	15.8	4.5	20.3	11.1	15.5	15.1	30.6	.066
7171	28.5	12.5	31.0	29.0	34.7	17.7	52.4	.075
5947	24.1	9.1	33.2	28.7	34.8	17.8	52.6	.066
5647	24.2	5.4	29.6	23.4	29.0	13.8	42.8	.062
7615	11.4	8.7	20.1	13.9	25.3	20.3	45.6	.064
7616	13.5	5.0	18.5	9.1	14.8	11.0	25.8	.064
7158	11.6	4.8	16.4	12.9	18.7	10.0	28.7	.065
7632	23.0	5.5	28.5	19.2	31.6	14.5	46.1	.064
Average	21.4	9.3	30.7	19.6	25.2	20.6	45.8	.066

Table 16. Relation of nitrogen removed by crops to nitric nitrogen formed in parts per million—Continued.

Soil No.	Removed by		Total	One percolation when corn cut	Found in percolation			Per cent nitrogen in soil
	Corn	Sorghum			0 to 8 weeks	8 to 16 weeks	Total 0 to 16 weeks	
982	44.5	18.2	62.7	1.7	1.7	55.8	57.5	.068
7614	36.4	26.6	63.0	6.0	3.1	3.1	6.2	.093
7358	31.6	8.3	39.9	20.8	21.4	3.7	25.1	.082
7360	147.0	20.9	167.9	51.4	125.4	18.8	144.2	.095
7339	14.0	11.8	25.8	12.5	20.5	23.1	43.6	.090
7229	33.7	12.6	46.3	45.0	40.6	27.1	67.7	.091
869	41.8	40.7	82.5	30.3	15.9	.66	22.5	.080
5960	58.1	12.9	71.0	29.2	50.8	27.8	78.6	.099
5959	36.6	22.3	58.9	36.1	59.4	22.8	82.2	.093
7116	29.4	11.0	40.4	25.9	34.7	18.7	53.4	.09
7352	31.2	7.2	38.4	18.7	36.9	13.7	50.6	.083
7127	25.5	12.0	37.5	17.8	40.5	31.4	71.9	.082
5939	32.0	22.3	52.3	30.9	78.9	47.0	125.9	.098
Average	43.1	17.4	60.3	27.1	44.0	20.3	64.3	.....
7161	27.5	7.2	34.7	24.5	29.8	25.4	55.2	.147
7613	52.4	21.0	73.4	19.6	22.8	37.8	60.6	.140
7356	43.9	14.3	58.2	37.8	64.3	36.8	101.1	.148
7223	27.5	4.3	38.8	38.8	49.6	28.8	78.4	.168
3342	41.1	12.9	54.0	18.5	55.5	37.3	92.8	.151
Average	38.5	11.9	51.8	27.8	44.4	33.2	77.6	.151
7621	26.3	6.8	93.1	33.1	25.3	16.8	42.1	.044
7351	27.3	6.5	33.8	21.8	19.9	15.2	35.1	.056
7619	18.3	5.4	23.7	20.5	20.1	13.7	33.8	.059
7622	23.5	3.6	27.1	11.3	16.1	0	16.1	.052
7342	23.2	5.7	28.9	12.3	18.4	19.4	37.8	.055
7709	17.6	7.6	25.2	12.9	20.0	12.5	32.5	.044
7239	18.9	8.6	27.5	21.6	20.4	20.7	41.1	.048
7226	36,1	7.9	44.0	40.4	20.7	13.2	33.9	.057
7354	17.6	3.1	20.7	4.2	0	0.4	0.4	.058
7349	21.6	5.4	27.0	24.7	21.6	11.6	33.2	.042
7343	17.4	4.7	22.1	17.3	11.7	8.8	19.5	.055
7166	19.2	4.6	23.8	22.3	25.6	12.1	37.7	.052
Average	22.3	5.8	28.1	20.2	19.9	13.1	33.0	.052
7347	20.4	12.0	32.4	21.4	25.6	21.2	46.8	.065
7714	18.5	16.9	35.4	44.9	45.2	29.0	74.2	.064

When the nitric nitrogen found by one percolation at the end of the period of growth of the corn, about two months, is compared with the nitric nitrogen found by the percolation at the beginning of the experiment, plus that found every four weeks thereafter, for eight weeks, the agreement is found to be remarkably close in the first two sets, but as the quantity of nitrates produced becomes larger, the differences become wider. Larger quantities of nitrates, as a rule, are produced when several percolations are made than when only one percolation is made at the end of the experiment. This does not occur with all soils, for with some soils the reverse occurs, as with soil 869. With other soils there is not a great difference. However, there are large differences with some of the soils. Soil 7360 produces 51.4 parts per million nitrogen as nitrates when allowed to remain to the end of the experiment, and 125.4 parts per million when percolated at the beginning of the experiment, at the end of four weeks, and at the end of eight weeks. This may be compared with 147.0 parts per million removed by the corn crop. Soil 3342 produced 18.5 parts per million in the one percolation, and 55.5 when the three percolations were made. This may be compared with 41.1 removed by the corn crop.

From these results the conclusion is drawn that the percolation at periods of four weeks is better than a single percolation. A similar comparison between percolation and jars is given on page 7 of Bulletin 259, and it is found that decidedly less nitrates were present in the jars. This is in accord with our general knowledge that products of bacterial action hinder bacterial growth, and removal of these products revives their action. There is also the possibility of denitrification.

On an average, the amount of nitrogen removed by the crop is remarkably close to the amount of nitrates produced in eight weeks. This is best shown when the averages for the groups are compared.

With the first group the corn takes up 21.0 parts per million, and the nitric nitrogen is 17.3 parts per million. In the second group, the corn takes up 26.3 and the nitric nitrogen is 19.9 parts per million. In the third group the corn takes up 21.4 and the nitric nitrogen is 25.2 per million. In the fourth group the corn takes up 43.1 and the nitric nitrogen is 44.4. In the last group, the corn takes up 38.5 and the nitric nitrogen is 44.4 per million.

Much larger differences are found when we compare the nitrates produced in the period from eight to sixteen weeks, with the amount of nitrates taken up by the sorghum crop which followed the corn. The amount of nitric nitrogen produced is twice as much as the nitrogen removed by the sorghum with three of the sets. With the fourth set, the amount of nitrogen taken up by the sorghum is nearly equal to the amount of nitric nitrogen formed in the percolators. In the fifth set, the amount of nitrogen taken up by the sorghum is about one-third the nitric nitrogen in the percolators.

The variations between the individual tests are much more decided than between the averages discussed above. In a number of the experiments the agreements between the amount of nitrogen removed by the corn, and the amount of nitric nitrogen available in eight weeks, is remarkably close. In other tests, the differences are much wider, and vary both ways. This may be seen by considering Table 16.

With a number of the soils the amount of nitric nitrogen produced in the percolators is less than the amount taken up by the crops. This is the case with soils 7715, 7231, 7354, 7343, 982, 7614, and 869. Soil 7354 did not nitrify, but the corn crop took up 17.6 parts nitrogen per million from the soil. Either the conditions for nitrification were more favorable in the pots in which the corn was growing, or the corn took up its nitrogen in other forms than nitrates in these particular pots. The writer is inclined to believe that the difference is due to conditions of nitrification, and that the growing crop favorably influenced the process with these particular soils. Perhaps the removal of nitrates and ammonia by the growing crop favorably influenced the process of nitrification, or perhaps the moisture conditions were more favorable. The behavior of soil 982 is evidence that such is the case, for it produced only 1.7 parts per million of nitric nitrogen in the first eight weeks, but more favorable conditions caused it to produce 55.8 parts per million in the second eight weeks, while the amount of nitrogen taken up by the corn crop was 44.5 parts per million of soil.

There are other soils in which the amount of nitric nitrogen produced is decidedly in excess of the nitrogen taken up by the corn crop. Soil 7714 produced 45.2 nitrogen as nitrates, but the corn crop took

up only 18.5. Soil 7615 produced 25.3, but the corn crop took up only 11.4 parts per million. Soil 5959 produced 59.4 and the corn took up 36.6. Soil 5939 produced 78.9, and the corn crop took up 32.0. Soil 7356 produced 64.3 and the corn took up 43.9. Either the corn crop did not take up all the nitrates formed, or the nitrification conditions were more favorable in the percolators than in the pots in which the corn was growing. It could hardly be expected that the corn crop would completely exhaust the nitrates of the soil, for such is not usually the case. Wright (Soil Science, 1920, 258) found large proportions of nitric nitrogen left in the soil after growing various crops.

NITRIFICATION OF MANY SOILS.

After the preliminary work discussed above had been completed, a large number of soils on other portions of which pot experiments had been made, were placed in percolators, and nitrified for three periods of four weeks each. To the nitric nitrogen already present in the soil, and extracted by the first percolation, was added that formed during the experiment, and this total is the amount under discussion in this bulletin. The growing crops have at their disposal the amount of nitrogen already present in the soil as well as that formed during the period of the growth. Bulletin 259 was a study of the production of nitrates in soils, and for this reason the nitrogen present in the soil at the beginning of the nitrification was not considered. The two bulletins differ in this respect.

The soils were arranged in groups differing .02 per cent. in total nitrogen content. The work was carried on during the late spring and early summer, when the weather was warm. As shown in Bulletin 259, weather conditions no doubt influence the production of nitrates.

RELATION OF NITRIC NITROGEN TO NITROGEN REMOVED BY FIRST CROPS.

The soils were arranged in groups differing 8 parts per million in the amount of nitrogen removed by the first crop, and the averages are given in Table 17. The average nitrogen taken up by the first crop ranges from 6.31 parts per million in Group 1 to 94.74 parts per million in Group 8. The available nitric nitrogen in parts per million is given in the table. By available nitric nitrogen we here mean the

Table 17. Average relation of nitrogen in first crop to nitrification and weight of crops.

Group based on nitrogen removed by first crop	Nitrogen per million			Available nitric nitrogen			Weight crops, gm.		Per cent nitrogen in soil	Number averaged
	In first crop	In second crop	Total	Per million of soil	Per cent taken by first crop	Per cent taken by first two crops	First crop	Second crop		
Group 1. 0–8	6.31	14.60	20.91	43.4	14.6	48.2	7.6	7.2	.058	5
Group 2. 8.1–16	12.68	5.15	17.83	23.2	54.7	76.8	13.0	2.8	.044	50
Group 3. 16.1–24	19.35	6.12	25.47	33.3	58.1	76.5	17.2	3.9	.052	47
Group 4. 24.1–32	27.76	8.01	35.47	44.6	62.3	80.2	23.7	4.9	.073	20
Group 5. 32.1–40	35.34	14.33	49.67	49.9	70.8	99.5	27.4	8.4	.087	16
Group 6. 40.1–48	43.66	11.14	54.80	69.9	62.5	78.4	26.9	7.8	.107	10
Group 7. 48.1–64	54.94	11.86	66.80	57.2	96.1	116.7	29.6	8.1	.062	14
Group 8. Over 64	94.74	29.13	123.87	124.5	76.1	99.5	36.4	20.7	.121	17

nitric nitrogen removed by the percolation at the beginning of the nitrification, added to that removed at the end of the four weeks, at the end of eight weeks, and at the end of twelve weeks.

With the exception of Groups 1 and 7, the amount of available nitric nitrogen increases regularly with the amount of nitrogen taken up by the first crop. The available nitric nitrogen in Group 1 is much larger than the amount of nitrogen removed by the first crop, but this permits the second crop, shown in the second column, to remove more nitrogen than any crop up to Group 8. It would appear from these results that the crops grown on the soils of Group 1 were limited by some other condition than the amount of nitrates in the soil.

The table shows that there is a distinct relation between the average amount of nitrates formed in the soil and the average amount of

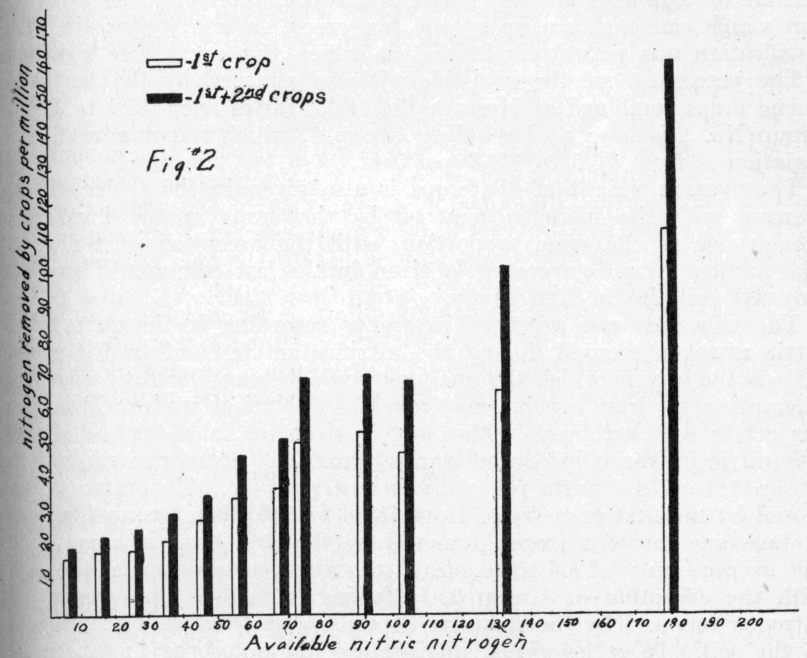

Figure 2.—Relation of nitrogen removed by crops to available nitric nitrogen produced by soil.

nitrogen removed by the first crop. The first crop was used as the basis of comparison for the reason that it has at its disposal approximately the same quantity of nitric nitrogen as was extracted from the percolators. The period of growth of the second and subsequent crops was much larger than the nitrification tests in the percolators.

The amount of nitrogen removed by the first crop, divided by the amount of nitric nitrogen in the soil, expressed in percentages, is given in the table. Fourteen per cent. of the nitric nitrogen was removed by the first crop in Group 1, 54.7 in Group 2, and 96.1 in Group 7. The percentages removed by the other groups vary from 58.1 to 76.1.

These figures also show the differences between Group 1 and the

other groups. In the first group the nitric nitrogen was taken up by the first crops to a much smaller extent than with the other groups.

The nitrogen in parts per million taken up by the second crop is shown in the table. The first group is out of line with the others on account of the excess of nitrates left by the first crop. The amount of nitrogen taken up by the second crops beginning with the second group increases from 5.15 to 59.13 parts per million, and the increase is regular with the exception of Groups 6 and 7.

The total nitrogen taken up by the first and second crops combined is also shown in the table. This may also be compared with the nitric nitrogen secured during the nitrification tests. It must again be recalled that the two crops were growing in periods of about four months, while nitrification occupied a period of about three months. The amount of available nitrates formed was not, therefore, the same as that which can be taken up by the two crops, since a longer time for nitrification was permitted the soil on which the crops were growing.

The percentage of the available nitrates removed by the first and second crops combined as given in the table, varies from 48.2 to 116.7. Group No. 1 is lowest. Excluding Group 1, which is not normal, the variation is from 76.5 to 116.7 per cent.

The average weight of the crops is also given in the table. These increase with the nitrogen removed by the crops in the first crop, though not in the same proportion, with the exception of Group 6. The number of soils averaged is given in the last column. There are only five soils in the first group.

The soils were also arranged in groups according to the quantity of nitric nitrogen secured during the nitrification tests of twelve weeks. This is the way in which the analyses would be considered, if one were attempting to draw conclusions from the analytical work. The average of the soils arranged in this way is given in Table 18. The average nitric nitrogen produced varies from 4.6 parts per million in Group 1 to 178.4 parts per million in Group 12. The nitrogen removed by the first crop varies from 16.36 to 110.89 in Group 12. The average amount of nitrogen removed by the first crop increases with the average amount of available nitric nitrogen present in the soil, with the exception of Group 1, including 11 soils. The amount of nitrogen removed by the crops in Group 1 greatly exceeds the amount in the soil. In other words, nitrification did not occur in the percolators so as to form nitrates equal to the nitrogen removed by the crops. This is true to a certain extent of Group 2, although not as great as Group 1.

The average amount of nitrates removed by the first crop, divided by the nitric nitrogen formed in the soil (including that present at the beginning) is also shown in the table. A corresponding figure was given in Table 17, but there the soils are arranged according to the nitrogen removed by the first crop, while here they are arranged according to the nitric nitrogen available in the soil. The first crop of Group 1 took up 355 per cent. of the nitrates produced in the soil. The first crop with Group 2 took up 118.5 per cent. of the nitrates produced in the soil. With the other groups the percentage of nitric nitrogen removed by the first crop varies from 46.1 to 74.5.

Table 18. Relation of nitric nitrogen to nitrogen removed by crops in parts per million and weight of crops in grams.

Group limits based on nitric nitrogen in soil	% N. in soil	Available nitric nitrogen	Nitrogen per million			Weight of crops in gm.		Percentage of available nitric nitrogen removed		Number averaged
			First crop	Second crop	First and second crop	First crop	Second crop	By first crop	By first and second crop	
Group 1. 0–10	.041	4.6	16.36	2.94	19.30	14.3	1.8	355.6	419.5	11
Group 2. 10.1–20	.038	15.2	18.00	4.65	22.65	16.9	2.6	118.5	149.0	29
Group 3. 20.1–30	.049	24.7	18.40	6.36	24.76	15.3	3.5	74.5	100.3	27
Group 4. 30.1–40	.055	34.4	21.76	7.37	29.13	19.6	4.7	63.3	84.7	34
Group 5. 40.1–50	.057	44.9	27.60	6.81	34.41	21.2	4.3	61.5	76.6	27
Group 6. 50.1–60	.079	55.4	34.03	11.98	46.01	25.9	7.5	61.4	83.1	11
Group 7. 60.1–70	.103	67.1	36.65	14.55	51.20	25.9	7.7	54.6	76.3	10
Group 8. 70.1–80	.085	73.5	50.22	18.71	68.93	24.2	12.5	68.3	93.8	9
Group 9. 80.1–100	.131	90.3	53.47	16.52	69.99	32.4	12.0	59.2	77.5	7
Group 10. 100.1–120	.086	102.2	47.13	21.10	68.23	21.8	13.0	46.1	66.8	7
Group 11. 120.1–140	.170	130.2	65.11	36.31	101.42	30.5	25.1	50.0	77.9	5
Group 12. 140.1–180	.133	178.4	110.89	50.55	161.44	35.7	20.2	62.2	90.5	6

The amounts of nitrogen taken up by the second crop, and by the first and second crops combined, are also given in the table. With the exception of Groups 5 and 9, the nitrogen removed by the second crop increases regularly with the nitric nitrogen available in the soil. A regular increase of the nitrogen taken up by the first and second crop combined is to be seen in the table, with the exception of Group 10, which is a little out of line. The total nitrogen taken up by the four crops likewise increases regularly with the nitric nitrogen available in the soil.

The nitric nitrogen available in the soil, divided by the nitrogen taken up by the first and second crops, is likewise shown in the table as percentage of available nitrogen taken up by the first and second crops combined. With Group 1, this is 419.5 per cent., with Group 2, 149.0 per cent., and with Group 3, 100.3 per cent. With the other groups it varies from 66.8 to 93.8.

CORRELATION BETWEEN THE AMOUNT OF NITROGEN TAKEN UP BY THE FIRST CROPS AND THE AMOUNT OF NITRATES AVAILABLE IN THE SOIL.

The correlation discussed in connection with the total nitrogen of the soil is probably the most satisfactory method of comparing results of this kind. A correlation table showing the relation between the nitric nitrogen of the soil and the nitrogen taken up by the first crop, is given as Table 19.

Table 19. Correlation Table. Available nitric nitrogen of soil and nitrogen removed by first crop.

Nitrogen removed by first crop	Available nitrogen in soils																																	
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	
6	1																																	1
12		6	6	4	2	2	1			1			1							1														24
18	4	1	6	8	9	9	4	1		1					1																			44
24		2	2	2	3	8	8	2	2		1	2						1																33
30	1				1	2	2	3	2	2	3																							16
36	1	1	1					2	2	1		1	2		2																			13
42		1	1		1	1	2		1			2																						9
48					1				1			3			1	1				1	1													9
54					1	1	1	1	2			1			1																			8
60								1									1	1																3
66		1		1																1														3
72													2				1																1	4
78												1									1													2
84																			1															1
90									1			1																						2
96																						1												1
102																	1																	1
108													1																					1
114																																		0
120																								2	1									3
126																																		0
132																													1					1
138																																		0
144																																		0
150																									1									1
156																																		0
	7	12	16	15	18	23	18	10	11	5	4	11	6	1	4	1	3	2	1	3	2	1	2	2	2	0	0	0	1	0	0	0	1	180

The coefficient R has also been calculated from this table with the result that R=.708±.025.

Table 15 shows the correlation between the total nitrogen of the soil and the nitrogen removed by the first crops, and the factor R for this table is .581±.033. There is thus a closer correlation between the nitrogen taken up by the first crop and the nitric nitrogen produced in the soil under the conditions of the work here described than there is between the total nitrogen of the soil and the nitrogen removed by the first crop.

The correlation between the nitrogen removed by four crops and the total nitrogen of the soil R is 0.653.

The determination of the amount of nitrates produced by the soil presents a method of forming an opinion as to the amount of nitrogen in the soil available to plants. Some of the soils are out of line, and deviate widely from the average, and soils of this character require further study.

CORRELATION OF SOILS GROUPED BY TOTAL NITROGEN.

It seemed possible that there might be a closer correlation between the available nitric nitrogen of the soil and the nitrogen removed by the first crops, if the soils were first grouped by total soil nitrogen, since there was also a correlation between the total nitrogen and the nitrogen removed by the first crops.

Only two groups of soils contained a sufficient number of soils to make a test, and even these were not large enough.

Table 20 is a correlation table for 56 soils, showing the relation between the available nitric nitrogen of the soil and the nitrogen removed by first crops on soils containing .041—.060 per cent. total nitrogen.

Table 20. Correlation Table. Available nitric nitrogen of the soil and nitrogen removed by first crop on soils containing .021–.04 per cent total nitrogen.

Nitrogen per million in first crop	Available nitric nitrogen in soils																				
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	
6																					0
12		4	5	1	1		2													1	14
18	2	2	4	8	3	2		1		1											23
24	1				2	2															5
30	1						1														2
36			1																		1
42		1	1			1															3
48								1				2									3
54							1	1	1												3
60																					0
66				1																	1
72																					0
78																					0
84																					0
90																					0
96																					0
102																					0
108													1								1
	4	7	11	10	6	5	4	3	1	1	0	2	1	0	0	0	0	0	0	1	56

Table 21. Correlation Table. Available nitric nitrogen of soil and nitrogen removed by first crop on soils containing .041–.06 per cent total nitrogen.

Nitrogen removed by first crop.	Avaliable nitric nitrogen of soils.																																	
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	
6	1																																1
12				2		1							1																				4
18	2			2	5	5	2	1																									17
24		1	2	2		3	6	2										1															17
30					1	1			1	1																							4
36										1																							1
42					1	1																											2
48														1																			1
54							1		1																								2
60																		1															1
66		1																															1
72																																1	1
	3	2	2	6	7	11	9	3	2	2	0	0	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	52

Table 21 is a correlation table for 52 soils, containing .041—.060 per cent. total nitrogen.

In the correlation for all 180 soils (Table 19) between the available nitric nitrogen and the nitrogen taken up by first crops:

The coefficient R is .708±.025.

In the correlations for 56 soils with .02—.040 per cent. total nitrogen:

The coefficient R is .407±.073.

In the correlation of 52 soils with .041—.060 per cent. total nitrogen:

The coefficient R is .556±.064.

The correlation is closer with soils containing .041—.060 per cent. total nitrogen than for soils with .021—.040 per cent. total nitrogen, but not so close for all the soils.

The difference is probably due in part to the number of soils taken, since one soil far out of line may affect the coefficient decidedly when only a small number are used.

In the examination of Tables 15 and 16 we found that crops grown on soils in Group 1, Table 15, did not take up the nitrates of the soil as well as the other crops. It is possible that some similar crops are scattered through the other groups. In Table 16 we found that a number of the soils, especially in Groups 1 and 2, and probably some in Group 3, took up much more nitrates from the soil than were formed in the nitrification experiments. These soils were exceptional as compared with the others, and require further study, and are discussed at the end of this bulletin.

EFFECTS OF CROPPING UPON NITRATE PRODUCTION IN SOILS.

After the pot experiments had been completed, the soils used were passed through a sifter, the roots were removed, and portions of the soils cropped were subjected to the nitrification at the same time and under the same conditions as a portion of the original soil. The objection of this work was to ascertain what effect the cropping had upon the nitrogen remaining in the soil as regards production of nitrates, and if nitrification tests would show the nitrogen removed by cropping.

The averages for the groups arranged according to the available nitrates originally found in the soil are given in Table 22. The ar-

Table 22. Relation of nitrates produced before and after cropping in parts per million.

Groups limits based on nitrate nitrogen in original soil	Per cent nitrogen in soil.	Nitrate nitrogen			Nitrogen removed by four crops	"Decrease" divided by nitrogen by crops per cent	Number averaged
		Before cropping	After cropping	Decrease			
Group 1. 0–10	.041	4.6	10.7	—6.1	26.56	0	11
Group 2. 10.1–20	.038	15.2	14.7	0.5	30.21	1.7	29
Group 3. 20.1–30	.049	24.7	15.9	8.8	33.75	26.1	27
Group 4. 30.1–40	.055	34.4	22.7	11.7	43.90	26.6	34
Group 5. 40.1–50	.057	44.9	25.6	19.3	47.93	40.3	27
Group 6. 50.1–60	.079	55.4	24.6	30.8	67.61	45.5	11
Group 7. 60.1–70	.103	67.1	24.6	42.5	74.35	57.2	10
Group 8. 70.1–80	.085	73.5	30.1	43.4	88.78	50.0	9
Group 9. 80.1–100	.131	90.3	40.4	49.9	99.42	50.2	7
Group 10. 100.1–120	.086	102.2	37.7	64.5	113.49	56.9	7
Group 11. 120.1–140	.170	130.2	41.6	88.6	146.92	60.3	5
Group 12. 140.1–180	.133	178.4	51.4	127.0	177.69	71.5	6
							183

rangement of this table is the same as in Table 18, and some of the figures of Table 18 are repeated for the purpose of comparison.

The nitric nitrogen produced in the soils after the four crops have been grown is shown in the table. In Group 1, the nitric nitrogen produced after cropping is greater than the nitric nitrogen available in the original soil. This confirms our previous conclusion concerning the soils of this group, namely, that nitrification takes place better in these soils carrying the crops than in the soils in the percolators. In Group 2, the nitrification produced after cropping is not much different from that produced before cropping. With the other groups, there is a decided decrease in the nitric nitrogen produced in the soil which had been cropped. The amount of this decrease increases regularly with the amount of available nitrates originally produced in the soil.

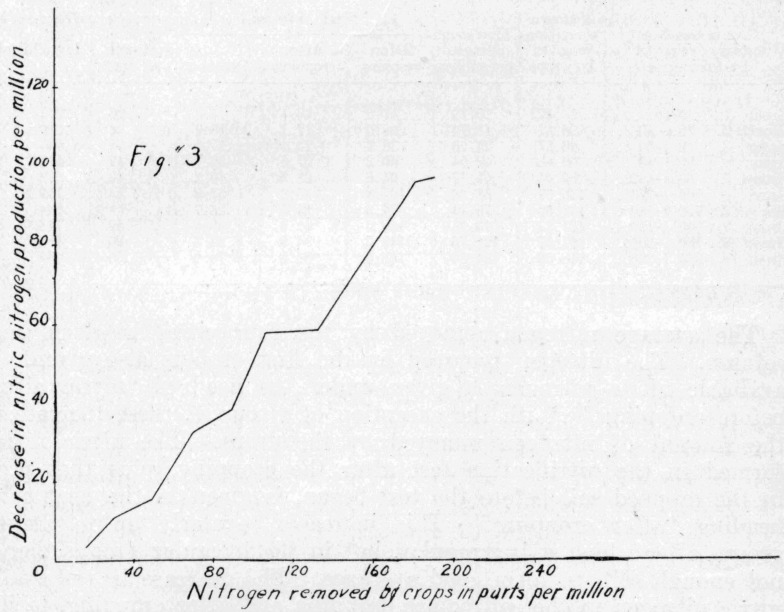

Figure 3.—Relation of nitrogen removed by crops to decrease in nitric nitrogen produced after cropping.

The differences between the available nitric nitrogen before cropping and the available nitric nitrogen after cropping show the effect of the cropping upon the soil as measured by the nitrification method. In the first group, composed of 11 soils, 4.6 parts per million of nitric nitrogen were available in the soil before cropping. After the removal of 26.56 parts per million of nitrogen by the crops, the cropped soil produced 10.7 parts per million of nitric nitrogen, or more than before cropping. The second group of soils also averages little or no loss. With the other groups there is closer relation between the decrease in the amount of nitric nitrogen produced and the total nitrogen removed by cropping.

The last column shows what percentage the decrease in available nitric nitrogen is of the nitrogen removed in cropping. In Group 2,

the average decrease is only 1.7 per cent. of the nitrogen removed. With Groups 3 and 4, the decrease is 26 per cent., and with the remaining groups the decrease ranges from 40.3 to 71.5 of the amounts removed by the crops. The cropping of the soil has, therefore, a decided effect upon the soil nitrogen as shown in the production of nitrates, and this effect can be followed by nitrification tests such as these described here.

In Table 22 the soils were arranged according to the nitric nitrogen produced in the soil. In Table 23 the soils are arranged in groups according to the nitrogen removed by the four crops, expressed in parts per million of soil.

Table 23. Average relation of total nitrogen removed by crops to nitrogen before and after cropping.

Groups based on nitrogen removed by four crops	Nitrogen per million removed by crops	First crop nitrogen per million	Nitric nitrogen			"Decrease" divided by total nitrogen per cent	Nitrogen in soil	Number of soils
			Before cropping	After cropping	Decrease			
Group 1. 0–20.....	14.97	10.13	17.2	13.4	3.8	25	.045	1
Group 2. 20.1–40....	29.82	15.79	28.6	17.7	10.9	36	.046	73
Group 3. 40.1–60....	48.57	24.96	38.7	23.5	15.2	31	.065	41
Group 4. 60.1–80....	69.83	42.94	60.2	27.5	32.7	47	.076	25
Group 5. 80.1–100...	89.04	45.77	66.6	28.5	38.1	43	.079	10
Group 6. 100.1–120...	106.07	58.23	102.8	45.2	57.6	54	.131	7
Group 7. 120.1–140...	132.60	73.35	74.2	25.5	58.7	44	.084	5
Group 8. 140.1–180...	181.33	73.23	140.6	42.6	95.5	59	.128	4
Group 9. 180.1–200...	191.97	126.70	149.5	51.8	96.7	50	.157	4
Group 10. 210.1–220...	218.09	104.35	138.3	55.8	78.0	36	.185	2

The average nitrogen removed by the four crops is given in one column. The nitrogen removed by the first crop is also given. The available nitric nitrogen is given under the head of "nitric nitrogen before cropping." With the exception of Group 7, these increase with the amount of nitrogen removed by the crops. The nitric nitrogen formed in the nitrification test after the cropping, plus that present in the cropped soil before the test began, is given in the next column heading "after cropping." This increases regularly up to the sixth group, after which it is irregular, but in the irregular groups there are not enough soils to form good averages. The decrease in the available nitric nitrogen in the soil before cropping and after cropping, is shown in another column, headed "decrease." This decrease becomes larger as the quantity of nitrogen removed by the crops gets larger. The relation is regular with the exception of Group 10, which contains only two soils.

The decrease expressed in percentage of the nitrogen removed by the four crops is given in another column. This decrease varies from 25 to 59 per cent. of the nitrogen removed by the crop. This method has, therefore, permitted us to trace the effect of cropping upon the nitrogen of the soil. The cropping has decreased the nitrogen which can be converted into nitrates. With many of the soils the relation is fairly constant.

Table 24. Correlation Table. Decrease in nitric nitrogen and nitrogen removed by crops in parts per million.

Total nitrogen removed by crops, parts per million	Decrease in nitric nitrogen formed																																					
	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	136	140	144	152	
10	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
20	3	5	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10
30	6	5	7	4	4	.	2	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30
40	3	4	4	5	3	4	.	.	.	.	1	1	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	27
50	.	5	4	3	3	2	2	3	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	23
60	1	2	1	2	3	1	2	.	2	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15
70	1	.	.	.	4	1	1	2	2	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13
80	.	1	.	2	2	.	1	.	.	.	1	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	11
90	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
100	.	.	.	.	.	.	1	.	.	.	1	.	.	1	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	5
110	.	.	.	.	.	.	1	.	.	1	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5
120	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
130	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
140	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
150	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
160	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
170	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
180	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
190	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	2
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	2
210	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
220	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
230	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
	14	22	18	18	19	10	11	5	6	3	6	1	1	3	3	0	4	1	2	1	1	2	1	1	0	1	1	0	2	0	0	1	0	0	0	1	1	160

CORRELATION BETWEEN THE NITROGEN REMOVED IN CROPPING AND DECREASE IN NITRIFICATION MADE AVAILABLE IN THE SOIL.

The correlation between the nitrogen removed by the crops and the decrease in nitrification of the soil has been worked out by the methods already described. The correlation table is Table 24. The correlation coefficient R is $.680 \pm .029$. This shows a good correlation between the two factors. Crops which produced more nitrate nitrogen after cropping than they did before cropping are not included.

The correlation between the nitric nitrogen available in the soil and the nitrogen removed by the first crop R is $0.708 \pm .25$.

RELATION OF THE NITRIC NITROGEN AVAILABLE AFTER CROPPING TO THE NITROGEN REMOVED BY THE THIRD AND FOURTH CROPS.

It was considered that there might perhaps be a relation between the amount of nitrogen removed by the third and fourth crops and the amount of nitric nitrogen produced in the nitrification experiment made after the soils had been cropped. The soils were accordingly arranged in groups according to the nitric nitrogen available after cropping, and averages taken. The results are given in Table 25. With the exception of Groups 1, 6, and 9, the nitrogen removed by the third crop is in the same order as the nitric nitrogen available after cropping. The nitrogen removed from the soils of the first group by the

Table 25. Relation of nitrogen removed by third and fourth crops to nitrate nitrogen produced after cropping, in parts per million.

Arrangement—nitrates after cropping	Produced after cropping	Nitrogen removed by		Per cent nitrogen in soil
		Crop 3	Crop 4	
Group 1. 0–6	4.7	4.9	3.0	.069
Group 2. 6.1–12	9.6	4.2	3.7	.039
Group 3. 12.1–18	15.3	6.3	4.3	.044
Group 4. 18.1–24	20.2	9.0	4.6	.050
Group 5. 24.1–30	26.7	10.2	7.2	.080
Group 6. 30.1–36	31.9	9.3	9.8	.067
Group 7. 36.1–42	39.1	13.4	5.3	.102
Group 8. 42.1–48	45.9	15.7	10.8	.154
Group 9. 48.1–54	50.1	11.2	7.5	.094
Group 10. 54.1–up	65.8	24.1	17.1	.156

third crop is equal to the nitrogen available after cropping, but with the other groups the third crop removed about two-fifths to one-fourth of the nitrogen available after cropping. It is seen that the nitrogen taken up by the third crop is not as much as the nitrification test would lead us to infer. The first crop exhausted the nitric nitrogen much more closely. The nitrogen removed by the fourth crop increases with the nitric nitrogen available, with the exception of Groups 7 and 9. The nitrogen taken up by the crop varies from two-thirds to about one-seventh of the nitric nitrogen available after cropping. It would appear that the conditions in the pots for nitrification for the third and fourth crops are not as favorable as they are in the percolation jars after cropping. It is possible that breaking up the soil and preparing it for the percolators placed it in a more favorable condition for nitrification than it was in the pots.

Table 26. Correlation Table. Nitrogen taken up by third crop and nitrate nitrogen produced after cropping.

Nitrate nitrogen produced after cropping.	Nitrogen taken up by third crop in 0.1 gram																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
4		1																											1
8	1	5	2	4																									12
12	2	5	9	1	1																								18
16		6	9	5	3		1																						24
20		6	8	5	6	3		1		1																		1	31
24			11	4	2	2			1																				20
28		1	4	3	2	2	4	2	1		1										1								21
32		1	4	4	2	5	2	1																					19
36			1		1	2	2																						6
40			1	1		2													1										5
44				1	1	1		1																					4
48								2	2	1																			5
52		1			1			2																					4
56																													0
60													1	1							1								3
64									1		1																		2
68						1															1								2
72													1																1
76																													0
80																													0
84																													0
88																													0
92																													0
96				1																									1
	3	26	49	29	19	18	9	9	5	2	2	0	2	1	0	0	0	0	1	0	3	0	0	0	0	0	0	1	179

CORRELATION BETWEEN THE NITROGEN TAKEN UP BY THE THIRD CROP AND THE NITRIC NITROGEN AVAILABLE AFTER CROPPING.

Table 26 shows the correlation between the nitrogen taken up by the third crop and the nitric nitrogen found in the nitrification test after cropping. The coefficient of correlation calculated from this table, R, is .538±.036.

PRODUCTION OF AMMONIA.

Some of the soils reported in Bulletin 259 did not nitrify, and the question arose whether ammonia was produced in these soils to a greater extent than in soils in which nitrification occurred. The question also arose whether the ammonia nitrogen in the soil, added to the nitrate nitrogen, would not be a better measure of the nitrogen availability than the nitrate nitrogen alone. For these reasons the study of the formation of ammonia nitrogen was taken up in connection with the formation of nitric nitrogen.

Preliminary Work.—It was desired to conduct the ammonia work parallel with nitrification work by making an estimation of ammonia in the filtrates on which the nitrates were determined. While it was recognized that all the ammonia would not be removed from the soil by the water, it was at the same time considered that the ammonia left behind would be either removed at a subsequent percolation, or else converted into nitrates and then removed.

In order to ascertain the amount of ammonia which would be retained by soils, two portions of the same soil were placed in percolators and one sample percolated with water, the other with very dilute ammonium chloride. The ammonia was determined by the colorimetric method described below. The soils were percolated with (a) distilled water, (b) with ammonia solutions containing about 20 parts per million of ammonia nitrogen in the form of ammonium chloride, and (c) with solutions containing about 50 parts per million of ammonia nitrogen. The results of this test are shown in Table 27. As was to be expected, the percentage of ammonia nitrogen absorbed by the soils was quite high.

It is therefore to be expected that the ammonia removed by water in percolating the soils in these experiments may not represent all of the ammonia nitrogen formed in the soil, but possibly only a small percentage of it; but any ammonia left behind should eventually be recovered as nitrates.

After various preliminary work the following method was adopted for the ammonia nitrogen in soils.

DETERMINATION OF AMMONIA.

Reagents.

Ammonia-free Water. A.—Acidify distilled water with sulphuric acid and distill in a room free from ammonia, rejecting the first 100 c.c. Preserve in glass-stoppered bottle.

Ammonia-free Water. B.—Add 10 c.c. sodium carbonate solution

(5 per cent.) to 1000 c.c. water. Evaporate about 750 c.c. and cool. Preserve in glass-stoppered bottle.

Standard Ammonium Chloride.—Dissolve 1.91 gms. ammonium chloride in 1 liter ammonia-free water, A. 1 c.c.=0.5 mg. N. Take 10 c.c. and dilute to 1000 with ammonia-free water A or B. 1 c.c.=.005 mg. N.

Table 27. Ammonia nitrogen absorbed from solution by soils.

		Ammonia nitrogen in solution used							
		18.0		23.3		13.8		51.7	
		Ppm. in solution	% absorbed	Ppm. in solution	% absorbed	Ppm. in solution	% absorbed	Ppm. in solution	% absorbed
853	First percolate	6.25	65.3	1.56	93.30	7.50	45.4	0.78	98.5
853	Second percolate	1.38	92.3	2.53	89.20	0.83	94.0	1.63	96.9
855	First percolate	3.17	82.4	.....	.....	4.88	64.5	.....	.....
855	Second percolate	2.00	88.9	.....	.....	1.88	86.9	.....	.....
858	First percolate	14.50	19.4	10.00	57.00	12.50	9.1	19.00	63.8
858	Second percolate	12.25	31.9	10.00	57.00	9.38	31.8	23.50	55.2
876	First percolate	7.00	61.1	4.75	79.60	6.25	54.5	3.50	93.3
876	Second percolate	3.00	83.3	4.25	81.29	6.25	56.1	5.88	88.8
923	First percolate	.....	.....	4.25	81.29	.....	.....	10.00	80.9
923	Second percolate	.....	.....	2.69	88.43	.....	.....	11.40	78.3
924	First percolate	.....	.....	3.75	83.87	.....	.....	1.40	97.3
924	Second percolate	.....	.....	1.33	94.28	.....	.....	5.20	90.1
925	First percolate	.....	.....	4.38	81.16	.....	.....	5.40	89.7
925	Second percolate	.....	.....	2.09	91.00	.....	.....	8.00	84.8
933	First percolate	.....	.....	4.38	81.16	5.10	62.9	3.75	92.9
933	Second percolate	.....	.....	5.20	77.63	5.25	61.8	6.00	88.6
936	First percolate	6.88	61.8	.....	.....	4.69	65.9	.....	.....
936	Second percolate	5.25	70.3	.....	.....	4.38	68.1	.....	.....
937	First percolate	17.00	5.6	.....	.....	10.00	27.3	.....	.....
937	Second percolate	7.50	58.3	.....	.....	6.25	54.5	.....	.....
941	First percolate	.....	.....	7.50	67.74	18.00	.....	5.30	90.0
941	Second percolate	.....	.....	7.75	66.67	8.75	40.0	20.00	61.9
942	First percolate	8.13	54.8	1.00	95.70	6.50	52.7	4.60	91.0
942	Second percolate	5.88	67.3	6.75	70.99	7.50	45.4	6.00	88.6
969	First percolate	5.50	69.4	2.69	88.43	4.00	70.9	3.25	93.8
969	Second percolate	2.76	84.7	2.56	89.00	2.50	82.6	4.25	91.6
981	First percolate	17.00	5.6	.....	.....	17.50	.....	.....	.....
981	Second percolate	11.50	36.1	.....	.....	8.00	41.9	.....	.....
1125	First percolate	3.13	82.6	.....	.....	.....	.....	.....	.....
1125	Second percolate	3.08	83.2	.....	.....	.....	.....	.....	.....
1267	First percolate	10.50	41.7	3.17	86.40	15.50	.....	8.00	84.8
1267	Second percolate	3.13	82.6	2.75	88.17	5.63	60.5	8.50	83.8
Solution used		18.00	.....	23.3	.....	13.8	.....	51.7	.....

Standard Colorimeter Solution.—Use 10 c.c. weak ammonium chloride, about 90 of ammonia-free water B and 4 c.c. Nessler's solution, diluting to 100 c.c. 100 c.c.=.05 mg. N (5 parts per million on 10 gms. soil).

Nessler's Solution.—Prepare by usual methods.

Analytical Process.—Make percolate up to 200 c.c., take 20 c.c., add 2 gms. magnesium oxide and 80 c.c. ammonia-free water. Distill off 50 c.c. Make up to 100 c.c. and take an aliquot. Dilute with ammonia-free water B, add 2 c.c. Nessler's solution, and compare with standard. Take a larger or smaller aliquot according to the ammonia to be expected.

Make a blank determination, using 80 c.c. water and 2 gms. magnesium oxide. Distill off 50 c.c., dilute to 100 c.c. and take 50 c.c. for the Nessler determination.

100 c.c. standard= 5 p. m. on 10 gms. soil (50 c.c.)
=25 p. m. on 2 gms. soil (10 c.c.)

PRODUCTION OF AMMONIA NITROGEN.

Table 28 shows the production of nitric nitrogen, and of ammonia nitrogen, in some soils which did not nitrify well, reported in Bulletin 259. The soils were always percolated at the beginning of the nitrification work, and the amount of nitrogen recovered is shown in the first column headed 0 under the head of nitric nitrogen, or ammonia nitrogen, respectively. The nitrification was conducted on five periods of four weeks each, and the ammonia determined in the first three of these periods. With soils 1126, 4596, 4586, 7132, and 1956 fair amounts of nitric nitrogen were formed during the last two periods.

Table 28. Nitrate and ammonia nitrogen in soils in parts per million in successive periods of weeks.

		Removed by first crop	Nitrate nitrogen							Ammonia nitrogen				
			0	1	2	3	4	5	Total	0	1	2	3	Total
1126	Subsoil	11.0	2.0	.0	.0	1.1	.....	8.3	11.4	6.85	.66	.33	.14	7.98
2347	Subsoil	9.8	4.7	.3	.7	.8	.....	1.1	7.6	2.05	.36	.15	.06	2.62
2351	Subsoil	10.7	1.2	.0	.0	.0	.0	.5	1.7	.41	.24	.03	.08	.76
3215	Subsoil	.....	.2	.0	.0	.2	.....	.5	0.9	.96	.15	.15	.08	1.34
3657	Subsoil	3.8	.0	.0	.....	.....	.....	.....	0.0	.05	.08	.....	.....	.13
4645	Subsoil	.....	13.9	.0	.0	.3	.0	.2	14.4	.17	.13	.06	.06	.42
4596	Subsoil	.....	.2	.0	.5	5.0	5.0	5.6	16.3	.58	.12	.05	.06	.81
4586	Subsoil	.....	.0	.0	.5	5.7	7.4	3.4	17.0	1.76	.05	.01	.02	1.84
7090	Subsoil	.....	.2	.0	.2	.2	.0	.3	0.9	2.58	.70	.23	.07	3.58
7132	Subsoil	.....	.0	.0	.0	1.3	5.0	4.1	10.4	.20	.12	.0	.02	.34
7354	Subsoil	.....	2.0	.3	.2	.7	.0	.5	3.7	1.42	.22	.0	.01	1.65
1956	Surface	.....	1.7	8.8	2.5	3.2	2.2	4.2	21.7	1.40	.10	.01	.03	1.54

The ammonia nitrogen recovered varies from .05 to 6.85 parts per million in the first extraction before the nitrification had begun. The ammonia produced during the regular nitrification periods was very small, not much more than one part per million for even the highest. While there was some ammonia already present in the soil at the beginning of the test, there was little or no production of ammonia during the period of nitrification. The amount of ammonia present in most of these soils was comparatively small, and could practically be left out of consideration.

The amount of nitrogen removed by the first crop is also given in the table for such of the soils as were cropped. This also is not large, but the ammonia formation does not throw any further light upon the matter. With soil 2351, 7.7 parts per million of nitrogen was removed by the first crop, the total amount of nitric nitrogen formed was 1.7, while the ammonia nitrogen present and formed was 0.76 per million. The additional determination of ammonia nitrogen gave practically no additional information. With soil 3657, the amount of nitrogen removed by the first crop was 3.8 parts per million, the amount of nitrate nitrogen formed was 0, and the amount of ammonia nitrogen was .13. Here again the ammonia determination gave little further information.

It might be objected to the above that the soils studied did not produce much available nitrogen anyhow for the crops, so that the total amount of available nitrogen that could be expected in the ammonification would not be large, but that if soils containing larger amounts

of available nitrogen were studied, more significant amounts of ammonia would be secured.

On account of the above consideration, the ammonia nitrogen was determined in connection with the nitrification on 116 soils before cropping and about 117 soils after they had been cropped.

The amount of ammonia nitrogen secured during the first period of nitrification was usually less than 0.1 parts per million. For this reason the ammonia determination was not made after the first period of four weeks.

A list of these soils is given in Table 29. Out of 233 soils there were 25 soils which produced more than .1 part per million of ammonia nitrogen during the first nitrification period of four weeks, and of these 25, 8 produced over 2 parts per million, and only 3 over 5 parts per million.

The figures in the first column of the table are for the first percolation, at the beginning of the experiment. Of the 116 soils before cropping, and 117 soils after cropping, only 20 soils before cropping and 1 after cropping contained more than 5 parts per million of the ammonia nitrogen. These are listed in Table 30. This includes both the ammonia nitrogen at the beginning of the experiment and that formed during the first percolation period. Table 30 also shows the nitric nitrogen produced during the nitrification of three periods of four weeks each added to that originally present in the soil. It also shows the amount of nitrogen removed by the first crop.

Table 29. Soils which produced over 0.1 parts per million ammonia nitrogen in four weeks.

	At beginning	End of four weeks
2350	2.94	.30
1934	0.11	0.37
3331	0.96	0.11
7090	1.91	1.30
11028	1.00	0.12
334	20.78	.12
6680	3.62	4.80
7235	6.92	1.33
7180	2.27	1.63
3632	5.58	0.15
6268	4.94	2.32
7094	0.11	0.81
7113	0.25	7.32
7173	0.13	6.22
3412	0.15	1.12
7093	0.05	2.85
7256	0.06	0.88
7109	0.03	0.46
11095	0.06	0.88
11096	0.02	2.91
11097	0.05	0.52
11098	0.02	0.63
11099	0.02	0.17
11101	0.02	0.50
1119	7.92	3.65
6268	4.77	15.40

With a few of these soils the addition of ammonia nitrogen to the nitric nitrogen explains why the first crop took up more nitrogen than was present in the nitrates. For example, with soil 981, the first crop took up 49.3 parts per million of nitrogen while the nitric nitrogen available was 49.9. If the nitric nitrogen alone is considered, the first

crop apparently exhausts the available nitrogen completely, but if the ammonia nitrogen is taken into consideration, there is an excess of about 13 parts per million of available nitrogen.

With soil 894, the available nitric nitrogen is 72.9 and the nitrogen taken up by the first crop 72.02. The ammonia nitrogen, however, is 21.77.

With soil 1119, the available nitric nitrogen is 34.6, and the nitrogen removed by the first crop, 40.32. The ammonia nitrogen is 13.01.

With soil 962, the available nitric nitrogen is 46.7 and the nitrogen taken up by the first crop, 48.16. The ammonia nitrogen is 5.63.

With these four soils, the determination of the ammonia nitrogen explains why the first crop should take up as much nitrogen as is present as the available nitric nitrogen, or more. In these soils the available nitric nitrogen does not represent all of the available nitrogen that is present in the soil.

With the remainder of the 21 soils listed in Table 30, the determination of the ammonia nitrogen throws no particular light on the matter.

Table 30. Soils which contain ammonia nitrogen in excess of 5 parts per million.

	Set	Ammonia nitrogen		Nitric nitrogen available	Nitrogen in first crop
		Beginning	4 weeks		
981	83	12.56	.07	49.9	59.28
4689	83	8.03	.03	30.4	13.68
7250	83	8.09	.04	80.6	42.66
1137	84	8.74	.01	75.3	11.02
1135	85	6,79	.02	38.3	26.46
7129	86	8.24	.01	.....	.....
11015	86	22.34	.03	.....	.....
894	87	21.56	3.21	72.9	72.02
7112	87	11.23	.03	33.1	23.0
334	90	20.78	0.12	267.9	84.64
7235	91	6.92	1.33	71.9	38.18
7232	92	6.10	0.08	24.9	13.52
7089	93	29.92	0.09	58.9	14.74
1119	94	12.91	0.10	34.6	40.32
7175	97	9.65	0.03	38.6	19.26
7095	99	6.07	0.01	19.8	12.88
1119	101	7,92	3,65	.....	.....
962	93	5.52	.07	46.7	48.16
7128	93	5.25	.90	20.4	14.90
3632	94	5.58	.15	63.9	20.80
3361	96	5.02	.09	36.6	15.20

Only one-sixth of the 117 soils contained more than 5 parts per million of ammonia nitrogen at the beginning of the experiment, and very few of them produced any ammonia nitrogen, or enough to require consideration. Of the 21 soils containing more than 5 parts per million of ammonia nitrogen, only four were of any particular significance. With the others, the determination only decreased the percentage of total available nitrogen that was removed by the first crop.

From the above work we conclude that the determination of ammonia during the process of nitrification as carried out by us is usually unnecessary. The determination of ammonia removed by the first percolation might be of significance in particular cases, but usually it is of little significance, and may be disregarded.

CORRELATION BETWEEN AMMONIA AND NITRIC NITROGEN AVAILABLE IN THE SOILS, AND THE NITROGEN REMOVED BY THE FIRST CROP.

The object of this study was to ascertain whether the determination of ammonia nitrogen in addition to the nitric nitrogen gave better correlation between the total available nitrogen and the nitrogen removed by the first crop than does the nitric nitrogen alone. For this purpose correlation Table 31 was prepared. Only 95 soils were available for this work, which is half the number available for the correlation with available nitric nitrogen.

Table 31. Correlation Table. Nitrogen removed by first crop and ammonia and nitric nitrogen produced by soil

Nitric and ammonia nitrogen parts per million	Nitrogen in first crop, parts per million															
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	
6	1	....	2	1	....	1	....	....	....	....	....	....	....	....	....	5
12	....	2	1	....	....	....	1	....	....	....	....	....	....	....	....	4
18	....	6	2	....	....	....	....	....	....	....	....	1	....	....	....	9
24	....	4	3	1	....	....	....	....	....	....	....	....	....	....	....	8
30	....	....	4	2	....	....	....	1	....	....	....	....	....	....	....	7
36	....	1	9	3	....	....	....	....	....	....	....	....	....	....	....	13
42	....	1	4	4	1	....	1	....	1	....	....	....	....	....	....	12
48	....	1	2	3	3	2	1	....	....	1	....	....	....	....	....	13
54	....	....	....	2	....	....	....	....	1	....	....	....	....	....	....	3
60	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	2
66	....	....	....	....	....	....	....	1	1	....	....	....	....	....	....	2
72	....	....	....	1	2	....	....	3	....	....	....	....	....	....	....	6
78	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	1
84	....	....	....	....	....	....	1	....	....	....	....	1	....	....	....	2
90	....	1	1	....	....	....	....	1	....	....	....	....	....	....	....	3
96	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	1
102	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	1
108	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1
114	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
120	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
126	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
132	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
138	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
144	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
150	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
156	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0
202	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	1
302	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	1
	1	17	29	17	6	5	4	6	3	2	0	4	0	0	1	95

The correlation coefficient for the total available nitrogen (including both the ammonia nitrogen and the nitric nitrogen) and the amount of nitrogen removed by the first crop, R, is .698±.036. The corresponding factor for the correlation between the nitric nitrogen available and the nitrogen removed by the first crop, R, is .708±.025.

There is thus a slightly closer correlation between the nitric nitrogen available and the nitrogen removed by the first crop than between the total available nitrogen and the nitrogen removed by the first crop. This may be due to the fact that a greater number of soils was included in the correlation table for the nitric nitrogen. But since equally as good correlation can be secured by considering the nitric nitrogen alone, and since the amount of ammonia nitrogen produced under the conditions of these experiments is usually small, we may safely conclude that the ammonia determination may be left out of consideration in work of this kind. Only in special cases need the determination of ammonia be made.

IRREGULAR SOILS.

There are two classes of soils with which the relation between the nitrate production and the amount of nitrogen taken up by the crops is not sufficiently close. In one class, the amount of nitrogen taken up by the crop is much less than the amount produced in the nitrification test. In the other class, the nitrogen taken up by the crops considerably exceeds the amount produced by the nitrification test. If the causes of these differences could be ascertained, and corrected, the correlation between the nitric nitrogen produced in the nitrification tests and the amount of nitrogen taken up by the crops would be much closer. The discussion of these soils has been delayed to the end of the bulletin for the reason that preceding work might throw some light upon the matter.

Soils of the first group, which took up much less nitrogen in the first crop than the amount of available nitrogen produced in the nitrification test, are shown in Group 1 in Table 17. The five soils of this group produced on an average 43.4 parts per million available nitric nitrogen in the nitrification test, while the first crops took up only 6.31 parts per million. A similar relation is observed with Group 1 in Table 22.

Table 32 contains the five soils of Group 1, referred to above. An examination of this table shows that only two of these five soils, 3620 and 992, are decidedly out of line, and these are chiefly responsible for the irregular appearance of the group.

Table 32. Soils of Group 1, Table 17, where first crops take up less nitrogen than the soil contains nitric nitrogen.

		Nitrogen per million			Available nitric nitrogen per million	KD crop gm.		KDN first crop gm.	% nitrogen in soil
		First crop	Second crop	Total 1 and 2		First crop	Second crop		
9184	Subsoil.....	6.30	1.62	7.92	23.1	6.3	1.3	29.9	.046
7164	Subsoil.....	7.78	1.62	9.40	14.5	7.4	1.0	40.4	.038
7132	Subsoil.....	4.36	2.64	7.00	4.4	4.7	1.5	37.6	.045
3620	Subsoil.....	6.64	10.60	16.24	56.6	6.5	9.3	48.4	.122
992	Subsoil.....	6.50	56.54	62.04	118.7	13.0	22.8	29.9	.040
	Average.....	*6.31*	*14.60*	.....	*43.4*	*7.6*	*7.2*	.....	.058

Sample 3620 produced 56.6 parts per million of nitric nitrogen, but the first crop took up only 6.64 parts per million, but in another pot experiment on the same soil the first crop withdrew 34.4 parts per million of nitrogen. The difference, then, is due rather to the error in the pot experiment.

Soil 992 produced 118.7 parts per million nitric nitrogen and the first crop took up 6.5 parts per million, while the second crop took up 56.5 parts per million. Unfavorable conditions in some way prevented the first crop from utilizing the nitrogen, as shown by the second crop.

The second class of soils is those from which the first crop removed much more nitrogen than was formed in the nitrification test. This class is shown in the average of Group 1 of Table 18, and to a less extent in Group 2. In Group 1 the average available nitric nitrogen

is 4.6, while the crop removes 16.36 parts per million, or 355.6 per cent. of the available nitrogen is removed by the crops. In Group 2 the available nitric nitrogen is 15.2, while the first crop removed 18.00 parts per million, and the percentage of available nitric nitrogen removed by the first crop is 118.5. Group 1 contains 11 soils, and Group 2 contains 29. Another effect of these unusual features of the soils is shown in Group 1 and Group 2 of Table 22. After cropping, the amount of nitrification is larger than in the original soil. Apparently the cropping favorably affects the nitrification test. The nitrate nitrogen before cropping in Group 1, Table 22, is 4.6 parts per million, while after cropping it is 10.7. With Group 2 the nitrate nitrogen produced before cropping is 15.2, and after cropping 14.7. The crops removed 26 to 30 parts per million of nitrogen from the soil between these two tests.

Table 33. Soils of groups which yield more nitrogen to the crops than to the nitrification test.

		Per cent nitrogen in soil	Nitric nitrogen produced		Nitrogen per million			KP crops, gm.		Number of crops	Active P_2O_5 per million	Acid consumed per cent	Depth	Per cent lime	Acidity
			Before cropping	After cropping	First crop	Second crop	Total all crops	First crop	Second crop						
	Group 1														
3657	Unusual	.028	0.8	15.1	14.08	2.10	30.48	10.2	1.5	6	7.5	5.0	12–24	.23	0
7090	Unusual	.039	0.9	8.9	18.14	2.56	25.74	18.5	1.2	4	6.9	0	9–21	.11	600
6011	Unusual	.037	1.4	5.3	27.16	2.50	45.34	28.3	1.2	6	40.6	4.0	12–24	.08	400
8818	Unusual	.052	1.7	8.9	17.50	2.84	20.34	17.5	2.0	2	56.2	8.5	12–24	.42	0
7094	Unusual	.036	3.0	14.6	12.76	4.06	22.50	14.5	2.5	4	26.8	1.0	12–24	.12	200
7354	Unusual	.058	3.1	4.4	17.60	3.12	26.08	9.6	1.9	4	7.2	5.3	11–21	.25	0
7132	Usual	.045	4.4	18.7	4.36	2.64	11.04	4.7	1.5	4	12.5	6.0	6–18	.23	464
7253	Usual	.026	8.1	11.8	9.36	4.60	20.76	9.0	2.5	4	21.8	0.0	5–17	.26	200
2347	Unusual	.028	8.5	17.5	36.18	3.70	52.66	15.2	2.6	6	5.9	0.0	11–22	.10	200
3338	Unusual	.035	9.2	8.0	13.60	3.12	24.22	17.9	2.0	4	90.0	.....	12–24	.15	0
7174	Usual	.062	10.0	4.3	9.20	1.12	12.94	11.5	0.5	4	7.5	2.0	12–24	.13	690
	Average	.040	4.6	10.7	16.36	2.94	26.56	14.2	1.8	4	.....	.....	.....	.....	.....
	Group 2.														
7172	Unusual	.099	12.2	5.3	25.60	10.26	57.62	17.8	5.9	4	8.7	10.4	6–16	.27	0
914	Unusual	.045	11.5	28.1	63.76	7.16	82.96	46.2	5.7	4	40.0	2.55	0–10	.18	0
7093	Unusual	.036	11.4	12.9	16.02	7.28	28.80	17.8	3.5	4	25.0	1.5	0–12	.17	215
7231	Unusual	.028	12.6	12.9	30.96	4.54	42.88	29.2	2.7	4	27.5	2.0	0–12	.54	0
7342	Unusual	.055	11.5	7.7	23.18	5.88	37.82	13.8	3.5	4	20.6	59.3	7–14	3.14	0
7622	Unusual	.052	14.7	6.3	23.52	3.60	33.48	21.0	2.0	4	17.5	1.5	8–12	.18	0
7619	Unusual	.059	15.3	15.0	18.30	5.36	35.80	17.6	2.8	4	20.3	2.5	0–6	.71	0
3656	Unusual	.021	17.7	21.7	36.56	8.70	62.46	35.7	6.9	4	13.81	3.5	0–12	.07	0
7349	Unusual	.042	18.1	12.8	21.58	5.44	39.46	18.6	3.2	4	36.3	.25	0–8–10	.28	230
	Average	.049	13.9	13.6	29.94	6.47	46.81	24.2	4.0	4	24.4	13.3	.....	.62	.....

Table 33. Soils of groups which yield more nitrogen to the crops than to the nitrification test.

		Per cent nitrogen in soil	Nitric nitrogen produced		Nitrogen per million			KP crops, gm.		Number of crops	Active P2O5 per million	Acid consumed per cent	Depth	Per cent lime	Acidity
			Before cropping	After cropping	First crop	Second crop	Total all crops	First crop	Second crop						
	Group 2														
7096	Usual	.011	11.7	9.5	11.92	6.32	24.46	14.9	1.4	4	11.2	.5	8–24	.04	0
7115	Usual	.022	10.2	15.5	11.72	3.14	21.26	12.2	1.8	4	21.8	1.5	10–24	.07	0
7109	Usual	.025	11.6	15.1	9.38	2.66	17.06	10.9	1.4	4	15.0	1.00	6–18	.06	230
3346	Usual	.036	12.0	28.9	11.92	3.74	24.64	14.2	2.2	4	93.9	2.9	12–24	.11	0
7130	Usual	.074	12.5	3.7	10.80	1.20	15.18	12.0	0.5	4	7.5	2.5	8–18	.11	464
7164	Usual	.038	14.5	6.6	7.78	1.62	12.74	7.4	1.0	4	25.0	2.0	12–24	.37	0
7149	Usual	.029	15.5	16.3	10.30	.....	22.74	10.5	.1	4	25.6	1.2	0–6	.13	0
7168	Usual	.025	12.4	13.9	10.06	2.80	23.06	11.7	1.5	4	91.2	.9	7–19	.07	0
7257	Usual	.035	14.3	16.3	12.32	4.38	22.58	11.4	1.9	4	41.9	.9	8–18	.17	0
7178	Usual	.039	15.9	14.1	9.16	3.69	22.58	10.9	2.0	4	16.2	1.4	6–12	.15	0
7707	Usual	.027	16.2	13.0	14.58	4.22	24.92	15.5	2.4	4	38.7	2.0	6–12	.31	0
7113	Usual	.035	16.9	16.5	10.24	2.92	15.94	12.2	1.5	3	10.0	1.00	6–12	.28	400
7350	Usual	.024	17.9	10.0	16.42	3.40	22.96	16.1	2.0	4	83.7	1.0	20–28	.31	0
8842	Usual	.040	17.9	15.7	14.30	4.72	18.52	13.0	2.1	2	9.4	.0	0–12	.02	0
7160	Usual	.046	18.9	48.1	19.32	3.12	28.16	17.7	2.2	4	39.4	10.0	8–20	.40	0
3362	Usual	.030	19.0	7.8	13.94	3.04	21.70	17.0	1.9	4	59.9	2.07	8–20	.15	0
7177	Usual	.027	19.4	9.5	12.48	4.02	27.00	13.0	3.0	4	27.2	1.7	0–6	.10	0
7095	Usual	.031	19.8	15.4	12.88	3.76	24.46	17.2	2.5	4	20.3	1.3	0–8	.12	200
7348	Usual	.029	19.5	11.2	16.12	3.72	27.18	15.5	2.0	4	38.4	.25	6–18	.22	0
7091	Usual	.031	19.5	16.0	17.46	10.14	37.66	19.4	6.5	4	16.8	2.5	0–12	.17	0
	Average	.033	15.8	15.2	12.66	3.82	22.74	13.6	2.0	4	34.7	1.9	.....	0.16	.....

The details of these groups are given in Table 33. In only one soil of Group 1, No. 7174, is the nitric nitrogen produced after cropping decidedly less than that produced before cropping. The amount of nitrogen taken up by the crop is slightly less than the amount of nitric nitrogen produced in the soil, so that this soil need not be considered as an unusual soil. Soil 7132 gave up about the same amount of nitrogen to the crop as was produced in the nitrification test, and the same is true with soil 7253, although both of these soils produced more nitrates after cropping than they did before cropping. If the soils of Group 1, producing less than 10 parts per million of nitric nitrogen, are considered, we find that of the 11 soils, 8 gave up more nitrogen to the first crop than is produced in the nitrification test, and 9 produced decidedly more nitrates after cropping than they did before cropping. For some reason or another, these soils did not produce as much nitric nitrogen in the nitrification test as they should have produced.

If we consider the soils of Group 2, producing 10 to 20 parts per million of nitric nitrogen in the nitrification test, we find that 9 give up more nitrogen to the first crop than found in the test, and 14 produced more nitric nitrogen after cropping than they did before cropping.

The correlation between the nitric nitrogen produced in the nitrification test, and the nitrogen taken up by the first crop, is more important than the decrease or increase in nitrate production caused by the cropping.

The soils of Group 2 are divided into two classes and each class is averaged separately. Class 1, unusual soils, includes those soils from which the crops take more nitrogen than was produced in the nitrification test, and Class 2, usual soils, includes those from which the crops took less than produced in the nitrification test.

No particular feature of the analysis could be taken to distinguish between the soils here called unusual and those called usual. Some are acid and some are not acid. Many in both groups are low in lime, while two unusual soils contain 3.14 and 0.71 per cent. lime, respectively.

Sometimes, in the nitrification work, the soils did not percolate well. Sometimes less percolate was secured than the 200 c.c. desired. In a few cases only 25 or 50 c.c. were secured; with still fewer, there were only a few drops. This matter was traced back to see if it would account for the soils termed "unusual." It did account for three soils of Group 1 and one of Group 2, but soil 7253 of Group 2, classed as "usual," also did not percolate well. However, these four soils (3657, 8818, 3338, and 7172) may be excluded on account of poor percolation. This reason could not apply to any of the others.

It was pointed out in Bulletin 259 that carbonate of lime (1 per cent.) eliminated conditions unfavorable to nitrification, and increased nitrification, but that it might also eliminate natural differences between soils.

Table 34 shows the effect of carbonate of lime upon soils which did not nitrify well, which were listed in Table 14 of Bulletin 259, but the amount of nitric nitrogen is not stated in the same way. The nitric nitrogen present in the first percolation is added in the results given in Table 34, as with all cases reported in this bulletin. But this was

Table 34. Nitric nitrogen produced with and without calcium carbonate on soils which did not nitrify well.

	Total 4 weeks no carbonate	Total 28 weeks carbonate added	Available nitric nitrogen	Nitrogen per million taken by first crop
1126	4.0	62.2	.....	11.0
2347	13.3	49.4	8.5	36.18
2351	1.5	43.0	.....	10.7
3976	0.0	42.6	.....	4.7
7090	0.5	27.3	0.9	18.14
7164	6.7	11.3	14.5	7.78
1138	2.1	185.2	.....	14.9

not the case with Bulletin 259, as it dealt with the production of nitrates.

With soils 2347 and 7090 there is a closer relation between the nitrogen removed from the soil by crops and the nitric nitrogen produced after the carbonate of lime was added than that produced before it was added. With soils 1126, 2351, 3976, and 1138 the reverse is the case. The matter requires further study, but from the results here reported it would appear possible that the addition of carbonate of lime in the nitrification tests might push the production of nitric nitrogen far beyond the amounts that the first crops would take up in the pot experiments, and thus the correlation would be poorer than without the carbonate of lime.

SUMMARY AND CONCLUSIONS.

1. This bulletin is the study of the relation of the total nitrogen of the soil, the nitrogen available in the form of nitrates, and the nitrogen available in the form of ammonia, to the nitrogen removed by crops in pot experiments.

2. The average weight of nitrogen removed by the four crops increases with the percentage of total nitrogen in the soil.

3. The first crop is much larger than the succeeding crops.

4. The average weight of the second crop on the soil containing the smallest amounts of total nitrogen is only 13.5 per cent. of the first crop, and the fourth crop is 11.4 per cent., while for the soils highest in nitrogen, the second crop is 68.7 per cent., and the fourth crop is 36.0 per cent. of the first crop. The differences are not so large when the nitrogen removed is considered.

5. Conclusions as to the needs of the soils for nitrogen as determined by pot experiments would depend upon the number of successive crops grown without nitrogenous fertilizer.

6. Crops of nearly the same weight of dry matter may vary considerably in nitrogen content, and the nitrogen of the crops should always be determined in pot experiments of this kind.

7. The four crops usually remove 6 to 9 per cent. of the total nitrogen of the soil or 1½ to 2 per cent. per crop.

8. On an average, the nitrogen of surface soils is better taken up than the nitrogen of subsoils. Subsoils are erratic, and may be much better or much poorer than the surface soils.

9. On an average, non-acid soils give up more nitrogen to crops

than acid soils, but many of the individual acid soils give up more nitrogen than the corresponding non-acid soils.

10. Little relation could be found between the nitrogen taken up by the soil and the active phosphoric acid of the soil, or the acid consumed, or the lime.

11. The amount of nitric nitrogen present in the soil at the beginning of the experiment, added to that produced in the percolators during three periods of four weeks each, was compared with the nitrogen taken up by the first crops.

12. There is a close relation between the amount of nitrogen removed by the first crop, and the amount of available nitric nitrogen. The nitrogen removed by the crops varies from 58.1 to 76.1 per cent of the nitric nitrogen with the exception of some groups out of relation with the others.

13. The soils used in the pot experiments were subjected to similar nitrification tests after the crops had been grown on them, and the results compared with the uncropped soils.

14. The effect of cropping is clearly shown by the differences between the nitrification before and after cropping. There is a relation between the decrease in the nitric nitrogen formed and the amount of nitrogen withdrawn from the soil by the crops grown upon it.

15. The nitrification test enables one to trace the effect of cropping upon the nitrogen of the soil.

16. The relation between the nitrates produced after cropping and the nitrogen removed by the third and fourth crop, is not as close as the relation between the nitrates available before cropping and the nitrogen removed by the first crop.

17. Ammonia was determined by colorimetric methods in a number of soils used in the pot experiments.

18. Considerable percentages of ammonia may be absorbed and retained from the percolation, but these would later undergo nitrification.

19. The amount of ammonia nitrogen secured during the first period of nitrification was usually less than .1 part per million, so that the ammonia determination was not made after the first period of four weeks.

20. In 233 soils, half of which had been cropped, 25 soils produced more than .1 part per million of ammonia nitrogen during the first nitrification period of four weeks; 8 of these produced over 2 parts per million, and only 3 over 5 parts per million.

21. Only 20 of the 233 soils had available more than 5 parts per million of ammonia nitrogen, including that originally present in the soil.

22. With a few of the soils, the determination of ammonia nitrogen offers some information, but with the majority of the soils the determination gives no particular aid. The determination appears to be unnecessary as a rule.

23. With some soils the amount of nitrogen taken up by the crops is much less than the amount produced in the nitrification test. This may be partly due to the unfavorable conditions during the pot experiments.

24. The amount of nitrogen taken up by the crops from some soils considerably exceeds the amount produced by the nitrification test.

These soils also produce more nitric nitrogen after cropping than they did before cropping.

25. Addition of carbonate of lime may increase the nitrification of some soils which produce less nitric nitrogen than the amount of nitrogen taken up by the crops, but the amount of nitrates produced may also greatly exceed the amount of nitrogen taken up by the crops, so that there is no better correlation than before. This matter requires further study.

26. In the correlation between the nitrogen content of the soil and the nitrogen taken up by the four crops as estimated by statistical methods, R is $.653 \pm .029$.

27. In the correlation between the total nitrogen of the soil and the nitrogen taken up by the first crop, R is $.581 \pm .033$.

28. In the correlation between the amount of nitrogen taken up by the first crop and the amount of nitrates available in the soil, R is $.708 \pm .025$. There is thus a closer relation between the nitrogen taken up by the first crop and the nitric nitrogen used than between the total nitrogen of the soil and the nitrogen removed by the first crop.

29. In the correlation for 56 soils with .021—0.040 per cent. total nitrogen between the available nitrogen of the soil and the nitrogen removed by the first crop, R is $.407 \pm .074$.

30. In the correlation for 52 soils with .041—.060 per cent. total nitrogen, between the nitric nitrogen and the nitrogen removed by the first crop, R is $.556 + .064$.

31. In the correlation between the nitrogen taken up by the third crop and the nitric nitrogen found in the nitrification test after the cropping, R is $.538 + .036$.

32. In the correlation between the nitrogen removed by the crops and the decrease in nitrification of the soil, R is $.680 + .029$.

33. In the correlation between the total available nitrogen, that is, the ammonia nitrogen plus the nitric nitrogen, and the amount of nitrogen removed by the first crop, R is $.698 \pm .036$ on 95 soils. The determination of ammonia gives no increased correlation over the determination of nitric nitrogen alone.